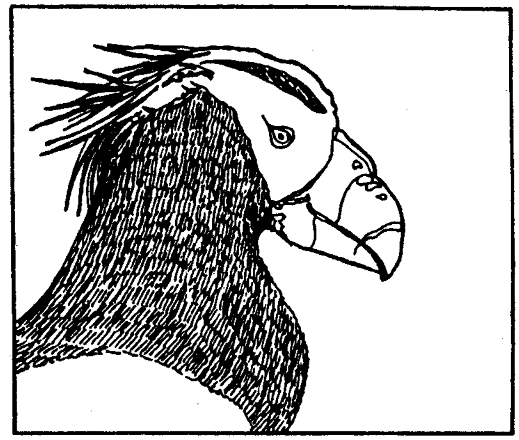
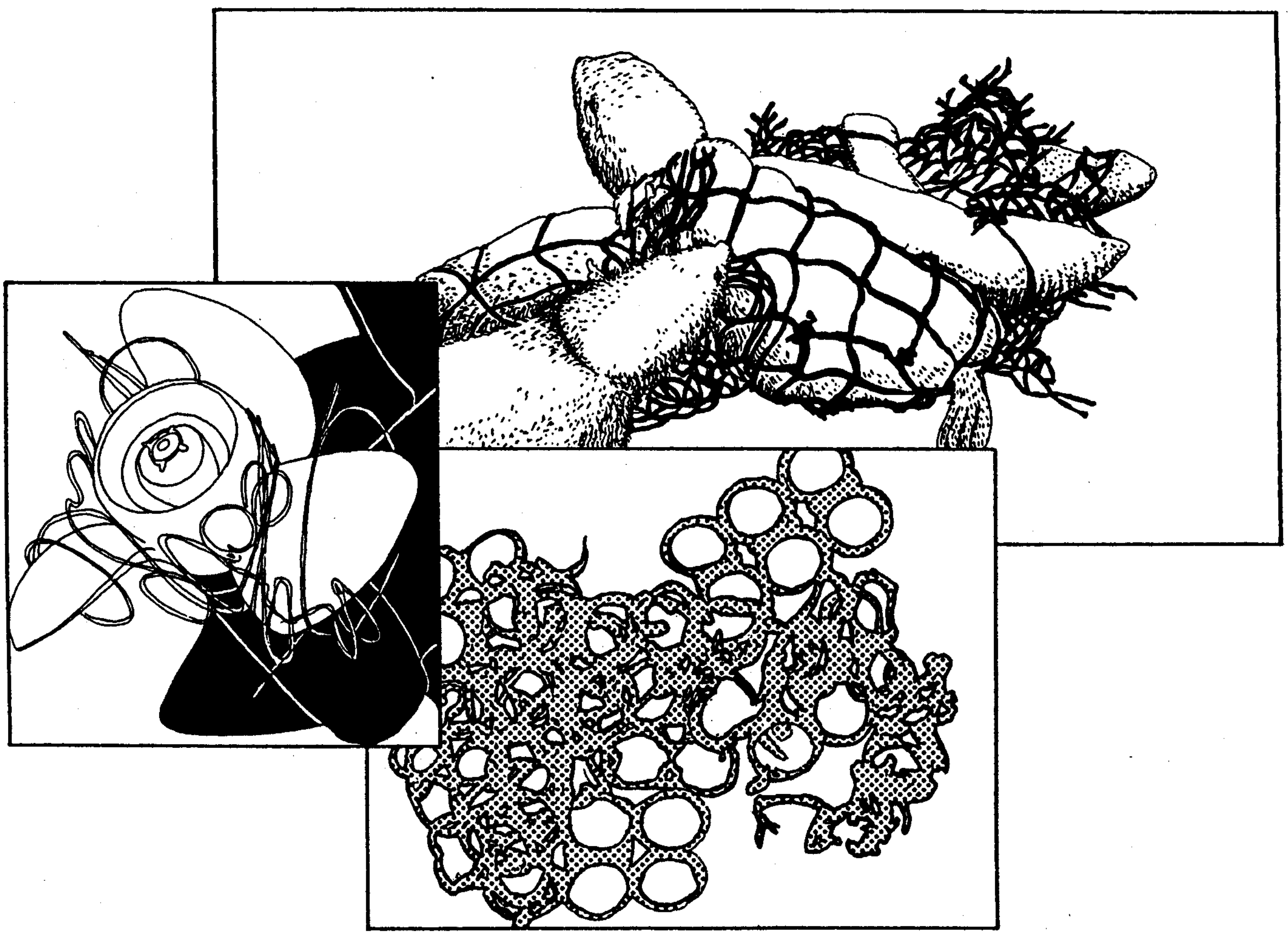


OVERVIEW PAPERS



A REVIEW OF MARINE DEBRIS RESEARCH, EDUCATION, AND MITIGATION IN THE NORTH PACIFIC

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ABSTRACT

The earliest biological investigations and reports of the marine debris problem focused on North Pacific species, principally seabirds and marine mammals. In 1984, the Workshop on the Fate and Impact of Marine Debris in Honolulu brought together scientists and managers to evaluate information on this problem. Based on the recommendations of the workshop this paper reviews research and management activities and results since 1984 in the North Pacific. The Governments of the United States and Japan have been the primary participants in these activities. Both United States and Japanese programs include research and monitoring, mitigation technology, and education, as evidenced by the variety of papers being presented at this conference. The effective implementation of the requirements of MARPOL Annex V, especially in the fishing industries of the North Pacific, is a common goal of most Pacific Rim nations. The fishing industries themselves have made significant commitments to address their contribution to the marine debris problem in the North Pacific. The effects of these actions on the known impacts of persistent debris in the North Pacific have yet to be realized.

INTRODUCTION

The early focus of attention in the marine debris issue in the United States was the North Pacific Ocean and its shores. This was due in large part to the early documentation of the interactions of wildlife with fisheries-generated marine debris. Observations of northern fur seals entangled in debris were recorded as early as 1936 (Fiscus and Kozloff 1972). Records of Laysan albatross ingesting plastic debris date from the mid-1960's (Kenyon and Kridler 1969). In 1974, field biologists began keeping records of entanglement of highly endangered Hawaiian monk seals (Henderson 1985). Widespread ingestion of plastic particles by 37 species of North Pacific seabirds was reported in a study by Day (1980).

In R. S. Shomura and M. L. Godfrey (editors), Proceedings of the Second International Conference on Marine Debris, 2-7 April 1989, Honolulu, Hawaii. U.S. Dep. Commer., NOAA Tech. Memo. NMFS, NOAA-TM-NMFS-SWFSC-154. 1990.

Starting in the early 1960's, large-scale industrial fisheries proliferated in the North Pacific and in the Bering Sea. Increasing use, loss, and discard of persistent plastic nets, packing straps, packaging, and other refuse from these vessels were evident in surveys of Alaskan beaches since 1972 (Merrell 1985). The general surface circulation patterns of the North Pacific suggest that floating debris may remain at sea for several years before being deposited on shore (Reed and Schumacher 1985). Accumulating evidence of increasing amounts of debris in the ocean combined with observations of its range of impacts on wildlife led to the convening of the first international scientific meeting on marine debris in late 1984.

The Workshop on the Fate and Impact of Marine Debris (FIMD), held in Hawaii in November 1984, was an opportunity for the scientific community to evaluate the state of knowledge about marine debris and to draw conclusions where appropriate (Shomura and Yoshida 1985). Based largely on data from the North Pacific, the working groups at the 1984 workshop concluded that persistent marine debris poses a long-term threat to certain species as well as to maritime and coastal commerce. Observations from other ocean areas suggested that similar problems could exist in all the world's ocean areas. These revelations fostered the initial concern about this new and apparently widespread form of marine and coastal pollution.

In response to the charge to participants, the 1984 workshop prepared a series of findings and recommendations that were to become the guidelines for marine debris action in the North Pacific as well as the world. The executive summary of the workshop report includes the following conclusory paragraph:

> "The Workshop considered the information presented during the technical sessions and concluded that there is ample evidence that debris of both terrestrial and shipborne origin are widespread in the marine environment. While such debris is known to interact with a wide variety of marine mammals, fishes, turtles, birds, and invertebrates, in most instances the consequences and quantitative impacts of this interaction do not appear to be well understood. However, substantial qualitative evidence indicates these interactions are contributing to increased mortality over that resulting from natural causes."

These findings prompted the workshop participants to make general recommendations for information collection to elucidate the sources, distribution, amounts, fates, and impacts of persistent marine debris. Studies of the biological impacts of entanglement and ingestion on North Pacific marine mammals, seabirds, and sea turtles were specifically identified. The development of sampling methodology for beach and sea surface debris--especially fishing gear--was recommended. In concluding that marine debris is a real problem for marine life and vessels, however poorly quantified, the workshop recommended education and mitigation efforts to be undertaken concurrently with the information collection activities. The mitigation efforts were to include regulation of the types of debris most hazardous to marine life, investigations of the use of biodegradable materials, net recycling, and the promotion of beach surveys and cleanups. Education efforts were recommended to advise user and interest groups of the nature and scope of the marine debris problem. The target groups were to include fishing and plastics industries, merchant carriers, the military, appropriate international organizations, and the public.

The workshop recognized that many of its findings were based on information from the North Pacific Ocean and recommended that the severity of the marine debris problem in other ocean regions be investigated. It also recommended a start on the evaluation of economic impacts of debris by obtaining data on worldwide vessel disablement caused by interactions with marine debris. The need for international cooperation in the investigation and solution of marine debris problems was broadly recognized by the workshop.

With the 1984 FIMD workshop as a starting point, this paper attempts to summarize and review recent marine debris research and monitoring, mitigation, and education activities affecting the North Pacific Ocean. This review includes known United States and foreign activities, brief summaries of their results, and an evaluation of developments and continuing needs in each action area. It is likely that there have been foreign government or industry actions addressing marine debris in the North Pacific that are not reported here. Any such omissions are unintentional. Many of these actions may be reported elsewhere in Shomura and Godfrey (1990).

RESEARCH AND MONITORING ACTIVITIES

Research related to marine debris problems has encompassed biological investigations, measurement of the sources, amounts and distribution of debris, and research and development for technological solutions. Under this section, biological research and the monitoring of debris sources and amounts will be reviewed. Research related to technologies for solving marine debris problems will be reviewed in the Mitigation section below.

Biological Research

Northern Fur Seal Entanglement

The United States, Japan, and the Soviet Union have carried out research related to the entanglement of the northern fur seal, *Callorhinus ursinus*. Until 1985, these research activities were coordinated under the Interim Convention on Conservation of Pacific Fur Seals. Since that time, cooperative research has continued between the United States and Japan at the Pribilof Islands, with each nation also doing independent research.

The northern fur seal population breeding at St. Paul Island in the eastern Bering Sea has been the subject of continuing study of the role of entanglement in fur seal population dynamics. Against a background of a declining population, the hypothesis that entanglement is a principal contributor to that decline was evaluated (Fowler 1985). Research to elucidate this relationship was primarily confined to the immediate vicinity of St. Paul Island during the summer breeding season.

Scientists from the United States and Japan continued cooperative studies on juvenile male fur seals in order to count and tag entangled seals. These studies (involving roundups) were necessary to simulate the juvenile male harvests which ended in 1984 but from which all previous entanglement rates had been calculated. A sample of nonentangled seals was tagged at the same time to allow for later evaluation of differential mortality based on resighting rates in future roundups. Roundups with tagging were conducted in 1985, 1986, and 1988. Resighting of these tagged seals provides data on the differential survival of entangled and nonentangled juvenile males. Roundups with removal of debris, starting in 1989, are expected to produce the tag resighting data necessary to estimate the changes in survival that may be possible through removal of debris for the period between weaning and the seals' first return to St. Paul Island.

Interpretation of the entanglement rates calculated from the roundups has been complicated by the possible differences in behavior of entangled and unentangled seals. Observations suggest that entangled seals may spend a larger proportion of their time away from the hauling grounds than their unencumbered counterparts. Studies in 1985 of entangled females with pups showed significantly longer feeding forays for entangled females and consequently less healthy pups. An experiment was conducted in 1988 using radio tags on entangled and unentangled juvenile males to measure differences in hauling behavior. Results will be useful in interpretation of prior years', roundup-based tag returns for calculating survival. These results are currently being analyzed with preliminary results presented by Fowler et al. (1990).

Without correcting for possible behavioral differences affecting the calculations, the entanglement rate for juvenile male fur seals has been near 0.4% from the late 1970's to the mid-1980's. Preliminary results for 1988 suggest that this rate may be decreasing due to less entanglement in waste trawl netting. Preliminary results and some interpretation of the tagging and differential mortality studies is presented in the Technical Session on Entanglement.

Both Japanese and United States scientists have carried out research on the behavior of fur seals leading to their entanglement. In 1986, an experiment in which fur seal pups were allowed to swim in a tank with various-sized pieces of netting showed that newly weaned pups were highly susceptible to entanglement in netting as small as 15 cm stretched mesh and that few were able to extricate themselves (Bengtson et al. 1988). Similar experiments in Japan with captive juvenile male fur seals showed that investigative behavior often led to entanglement, but many of these entanglements were temporary. In the Japanese experiments, the materials offered to the seals reflected the ranges of sizes found on naturally entangled, living seals. These experiments demonstrate the susceptibility of fur seals to entanglement in nets of various mesh sizes, and suggest that newly weaned pups may be at particular risk.

For most of the year, the northern fur seal population ranges across the entire subarctic Pacific. This makes coherent studies of at-sea entanglement arduous, expensive, and risky in terms of information return. Consequently, research on the entanglement of northern fur seals during their 9 months away from the Pribilof Islands has been minimal. At the Pribilof Islands, only the survivors are being investigated, giving a potentially biased view of the role of entanglement in population fluctuations. Research reviews and workshops in the United States to elucidate methods of inquiry that may be feasibly and economically applied to this question have been unsuccessful.

Recent data from the Pribilof Islands suggest that the fur seal population may have stabilized. Having been unable in the last 4 years to identify directly the role of entanglement in the fur seal population decline from the 1970's through the early 1980's, further entanglement research at the Pribilof Islands may be unproductive, although monitoring of entanglement rates as an index of hazardous debris changes should continue.

The question is certainly not closed. The impact of entanglement on 0- to 2-year-old fur seals while at sea remains one of the most serious marine debris issues. Resources permit only opportunistic gathering of data in the pelagic range of these animals. Reviews of remote sensing applications and other high technology approaches to this issue have shown them to be prohibitively risky or expensive. It is apparent that a complete, scientific assessment of the role of marine debris in population fluctuations of the northern fur seal will take many more years, if it can be done at all.

Northern Sea Lions

The northern sea lion, *Eumetopias jubatus*, population in the eastern Aleutian Islands has experienced a population decline of about 7% per year, similar to the northern fur seals at the Pribilof Islands. Unlike the northern fur seal, the northern sea lion population in the eastern Aleutians appears to have declined continuously since the 1960's. Concomitant decreases in other North Pacific population centers rule out emigration as an explanation. Entanglement in marine debris was hypothesized as a possible cause for this decline along with changes in prey availability, disease, direct killing by fishermen, and rookery/haul-out disturbances.

Since there were a few observations on record of entangled northern sea lions, surveys of the eastern Aleutian and Gulf of Alaska haul-out sites were conducted in June-July and November of 1985 (Loughlin et al. 1986). In the June-July survey, just over 30,000 sea lions were counted. Six were entangled and five more showed obvious signs of previous entanglement. The entanglement rate in this survey was 0.04% of the adult population. These data were judged inadequate to assess the magnitude of entanglement of sea lion pups because the survey took place before the pups had gone to sea for the first time.

The November survey was conducted to census fur seal and sea lion pups hauled out or stranded in the Aleutian Islands after weaning. This survey covered nine known haul-out locations and possible stranding sites but found no entangled fur seal or sea lion pups.

These results did help to clarify the role of entanglement in the northern sea lion population decline by suggesting a very low entanglement rate and a possibly high level of escapement from entanglement, at least in adults. Just as with the northern fur seal, the question of what may be happening to newly weaned sea lion pups at sea remains unclear.

Hawaiian Monk Seals

Classified as an endangered species under the U.S. Endangered Species Act (ESA), the Hawaiian monk seal, *Monachus schauinslandi*, is afforded special attention to protect it from entanglement. Since 1982, field biologists have collected, catalogued, and destroyed potentially entangling debris found at known monk seal haul-out sites in the Northwestern Hawaiian Islands (NWHI). Wherever possible, seals are freed from debris. Through 1984, records showed 35 incidents of monk seal entanglement, including 8 with scars of previous entanglements (Henderson 1985). From 1985 to 1987, another 19 entanglements have been observed, 3 of which resulted in the death of the animal (Henderson 1988). These 19 incidents represent an increase in the observed rate of monk seal entanglement despite the fact that many haul-out beaches in the NWHI are cleaned at least once a year.

Further information on the effects of entanglement on the Hawaiian monk seal are presented in Henderson (1990).

Seabirds

While there are scattered reports of seabirds being entangled in a variety of materials, the more widespread problem for seabirds is the ingestion of debris, especially floating plastics. Research on marine debris/seabird interactions undertaken in the North Pacific since the 1984 workshop has focused exclusively on the ingestion problem. In 1986, three specific studies of the impacts of plastic ingestion on the seabirds of Hawaii were undertaken cooperatively by the U.S. National Marine Fisheries Service (NMFS) and the U.S. Fish and Wildlife Service.

An evaluation of the incidence of ingested plastic in seabirds of the Hawaiian Islands was conducted between May 1986 and January 1987 (Sileo, Sievert, Samuel, and Fefer 1990). Prior to this study, only 2 of Hawaii's 22 species of seabirds had been thoroughly examined for ingested plastic. The study was able to examine 18 of Hawaii's 22 species, finding only 2 species with 0 plastic. The presence of plastic ranged from 0% in gray-backed and white terns and 1% in brown noddies to 94% in black-footed albatrosses. The data suggested that incidence of plastic in birds was related to the level of plastic in their immediate environment.

The other two studies of seabird ingestion of plastics involved the Laysan albatross population at Midway. Sampling of Laysan albatross chicks to determine diet, growth, and general health was initiated in 1987 to measure the relationship between plastic ingestion and growth, and plastic ingestion and mortality. This study continued in 1989, as the variability in the amounts of plastic fed by parent albatrosses to their chicks has been higher than expected. Chicks in 1987 had on average nine times more plastic in their diet than did 1988 chicks. Preliminary indications are that plastic ingestion may not contribute in any obvious way to chick mortality; its impacts on growth, however, may be detectable (Sileo, Sievert, and Samuel 1990; Sileo, Sievert, Samuel, and Fefer 1990).

Papers presented at this conference indicate that several species of North Pacific shearwaters have been studied for plastic ingestion (Ogi 1990). Further, investigations of seabird ingestion are underway in the South Atlantic by Ryan, in the South Pacific by Gregory, and in the eastern tropical Pacific and the Antarctic by Ainley and others. As in the North Pacific studies, there is, as yet, little evidence of direct damage to most seabird species caused by the ingestion of plastic debris. This indication is by no means proven, although broad acceptance of such a finding may be forthcoming. The working group on ingestion of marine debris is expected to address this generalization and recommend definitive research actions.

Cetaceans

In the period between the 1984 workshop and the current conference, little progress has been made in distinguishing between evidence of cetacean entanglement in marine debris and cetacean entanglement in active fishing gear. In most cases, the animal is encumbered by some fragment of fishing gear or rope but is found stranded on shore or adrift at sea away from any direct source. There has been no accumulation of records since the 1984 workshop to indicate that North Pacific cetaceans are threatened by marine debris through entanglement. A direct review of this phenomenon using all available information has not been undertaken. The value of such a review should be discussed in the working group on entanglement.

The subject of ingestion of marine debris by odontocete cetaceans was reviewed by Walker and Coe from 1987 through 1988 and is reported in the Technical Session on Ingestion in these Proceedings. While Walker and Coe (1990) found virtually no ingestion of debris by free-ranging pelagic odontocetes, they describe several cases of severe trauma to captive dolphins due to plastic ingestion. This review also finds that Baird's beaked whale, *Berardius bairdi*, and the sperm whale, *Physeter macrocephalus*, which feed in the benthos, commonly ingest foreign materials that have sunk to the sea floor. This work also suggests that the filter-feeding mysticetes may be at much greater risk of ingesting debris than their toothed cousins. A review of current worldwide information on the ingestion of foreign materials by the mysticete whales and the impacts of ingestion seems justified, as does further investigation of the benthic-feeding odontocetes.

Sea Turtles

Balazs (1985) summarized the body of information on entanglement in and ingestion of marine debris by all species of sea turtles. While the North Pacific is home to at least four of the seven species of sea turtles, all of which are protected under the ESA, the majority of research on the impacts of debris is being done in the southeastern United States. Because they are clearly vulnerable to entanglement (Balazs 1985), are relatively indiscriminate feeders (Lutz 1986), and are all endangered or threatened under ESA, sea turtles wherever they are found must be considered at serious risk from marine debris. Balazs and Choy (1990) provide an update on our knowledge about this problem for North Pacific sea turtles.

Research on the impacts of entanglement and ingestion on hatchling and juvenile sea turtles are being conducted by the Archie Carr Center for Sea Turtle Research at the University of Florida. This work is concentrating on the loggerhead turtle, *Caretta caretta*, in the Atlantic and will continue for at least 2 more years. The results of these studies regarding the role of convergence zones as debris sinks and sea turtle rearing areas may be generally applicable to other species of sea turtles, including those in the North Pacific.

Debris Sources and Amounts

The 1984 Hawaii workshop expressed concern about persistent debris at sea, on beaches, and on the sea floor. The principal focus of this concern was lost or discarded fishing gear, especially netting, traps, and ropes. These materials were judged to present the greatest hazard to marine life and ships through ghost fishing and entanglement. Since that time, research has been carried out to establish methods for surveying debris on beaches and at sea, systematic surveys have been conducted on beaches in Alaska, surveys of floating debris have been made from a number of vessels, a marine debris reference collection has been established, and trawl surveys of benthic debris have been completed.

Methods

A variety of approaches have been used to measure debris on beaches. Methods vary from geographic region to geographic region and from worker to worker. Most approaches have sound statistical underpinnings and reflect the experience and preferences of the survey initiator. Ribic and Bledsoe (1986) examined Alaskan beach survey data from Merrell (1980, 1985) and data from a number of sighting survey cruises in the North Pacific. They recommended methods for carrying out surveys of lost nets at sea and on beaches. Most of these recommendations focused on improving the ability to detect changes in debris density over time. From ship survey data for floating net sightings in the North Pacific and Bering Sea (Jones and Ferrero 1985), these workers calculated that net surveys in these regions would need to include at least 2,800 sampling units (1-h watches) in order to detect a reduction of 50% with 95% confidence. These surveys should be run annually and be designed to permit identification of, and stratification for, local concentrations of debris. This work also recommended that the suitability of aerial survey techniques for marine debris be evaluated.

Specific to entanglement problems in the North Pacific, the 1984 Hawaii workshop recognized the need for identifying the fishery of origin of nets and other fisheries materials found on animals and on the beaches.

In response to this need, the NMFS established a reference collection for fishing gear debris in the Alaska Fisheries Science Center in Seattle. Researchers with unidentified fisheries debris from the North Pacific may send a sample to the curator of this collection along with all pertinent information and receive an evaluation of its composition, the likely fishery of origin, and other pertinent information that may be available.

Debris Surveys

Since the work of Ribic and Bledsoe, there have been a large number of at-sea debris surveys, much of it from Japanese research and patrol vessels (Mio and Takehama 1988; Yagi and Nomura 1988). The surveys reported by Mio and Takehama involved 17 vessels covering 80,546 nmi in the North Pacific and recording 7,458 sightings, 1,584 of which were seaweed and 1,082 were wood, or 0.06 synthetic debris items of detectable size per track mile. Yagi and Nomura reported debris sighting data from vessels repeating a north-south transect from Japan to New Guinea from 1977 to 1986. This survey averaged 39 debris sightings annually in an average 4,000 km surveyed, or just under 0.01 items per track mile. An increasing trend in the number of plastic sheets and bags was identified in this series; however, no overall increase in plastic debris was obvious.

Cooperative research cruises each year since 1986 between the United States and the Republic of Korea and Taiwan have gathered data on the at-sea distribution of marine debris. These results are contained in the NMFS cruise reports (unpubl. data) but have not been consolidated or analyzed for time series or regional comparisons.

Some of the early research (Day 1980; Day et al. 1985) on ingestion of plastic particles by seabirds led to the speculation that a large amount of disintegrating plastic debris may be afloat in the convergence areas of the North Pacific. The density and characteristics of the microdebris were investigated by Day under contract to NMFS in 1987 and 1988. Samples were taken at 27 stations using neuston nets with mesh sizes in intervals down to 0.053 mm, and at 46 stations with mesh sizes in intervals down to 0.50 mm. In general, Day found areas of floating plastic particles all over the North Pacific, with the highest concentrations near Japan and just south of the Subarctic Front. The specific findings and interpretation of this work are reported in Day et al. (1990).

Ribic and Bledsoe (1986) concluded that "The usefulness of beach survey information is almost entirely dependent on the capability to infer ocean debris conditions from the beach information." The coordination of shipboard and beach surveys is essential if the utility of beach survey data is to be confirmed. Further, the lifetimes and dynamics of debris on beaches need to be understood if one is to conduct independent surveys over time in regions of interest. It may be necessary to remove or permanently mark debris to evaluate lifetime and movement as well as to ensure independence from survey to survey.

To date, there have been no coordinated ship/beach debris surveys to evaluate the relationship between amounts and types of floating and stranded debris in any region of the North Pacific. Johnson and Merrell (1988) report on time series of beach debris surveys from selected beaches in Alaska, where they cleaned sections of beach and also tagged large debris items. From this work they have been able to estimate the rate of deposition of entangling materials on certain Alaska beaches. At Yakutat, the deposition rate of trawl nets was estimated at seven nets/km/year. As a result of his debris tagging work, Johnson discovered that large net debris may be buried, uncovered, and moved along the beach by severe winter storms. Investigations into the dynamics of beached debris are continuing in Alaska and are further reported in Johnson (1990).

As part of the effort to protect Hawaiian monk seals from entanglement in debris, the research teams routinely survey, catalog, and remove nets, ropes, etc. from beaches in the NWHI. The net materials found in these surveys from 1982 to 1986 were reported by Henderson et al. (1987) and are updated by Henderson (1990). The collections through 1985 amounted to 632 nets or net fragments, 539 of which were poly, i.e., polypropylene or polyethylene, and 66 monofilament nylon. All of the monofilament net fragments were from gillnets and 54 of these were most likely from Asian squid and salmon driftnet fisheries. It was concluded that most of the poly nets and net fragments were from North Pacific midwater and bottom trawls. The fisheries of origin of this unexpectedly high proportion of trawl net materials on the beaches, and the ocean current systems that brought them to the NWHI, are yet to be established. Since the number of nets per kilometer of beach was quite high at several of the most important pupping beaches, and monk seals, unlike northern fur seals, entangle in a wide range of mesh sizes, the sources of poly fragments in the NWHI need to be understood and minimized.

Interest in the nature of accumulations of sinking debris on the Continental Shelf led to the enumeration of debris in bottom trawl surveys in the eastern Bering Sea in 1987 and off the U.S. west coast in 1988 (June 1990). These surveys were for groundfish abundance in areas of sand or mud bottom. The survey nets were set up to fish hard on the bottom, making it likely that debris in the upper few centimeters of the sediment would be scooped into the nets and be recorded. In general, the concentrations of sunken debris reflect the level of vessel activities in the areas. As one would expect, high traffic areas have greater debris densities than low traffic areas. Also, the types of debris found on the bottom generally reflect the surface activities.

In an attempt to elucidate the sources of net fragments in the North Pacific and the Bering Sea, a study of NMFS Foreign Fishery Observer Program data was conducted (Berger and Armistead 1987). The records from 1,068 observer cruises in 1982-84 in the U.S. exclusive economic zone (EEZ) provided data from every month of the year. The amounts of net discarded, lost, retrieved, or seen floating were recorded, as were net-mending activities and fishing operations. In 1982, 1983, and 1984, respectively, 14, 31, and 17% of the net pieces discarded were in the mesh size range to entangle fur seals. During this period, a total of 1,551 pieces of net were brought up in trawls and most were discarded back into the ocean. In 1983, foreign joint venture operations lost 70 trawl nets or large portions of nets. In 1984, this number increased to 90 nets. Foreign fishing in the U.S. EEZ has been almost completely displaced since 1984, but it is not known if the loss and discard rate of nets and net fragments has changed. Under the U.S. domestic law implementing MARPOL Annex V, it is illegal to discard net fragments, and one would therefore expect the amount of net input into the U.S. EEZ in the North Pacific to decrease in the coming years.

Another applied study of the disposition of derelict fishing gear in the North Pacific was reported by Gerrodette et al. (1987). In this study, a series of monofilament drift gillnets were attached to satellite transmitters and set adrift to simulate lost sections of squid or salmon driftnet. The purpose of the study was to gather information on the size, shape, location, and length of time in the ocean. Four nets, 50, 100, 350, and 1,000 m long were released on 12 August 1986 in the vicinity of Hancock Seamounts, northwest of the Hawaiian Islands. The nets were tracked by satellite from 57 to 309 days. The 50- and 100-m nets collapsed within hours of being deployed. The 1,000-m net was reduced to approximately 15% of its original length after 9 days adrift. It appears that there is a positive correlation between the length of the drifting section of gillnet and its ghost fishing effectiveness. The complex tracks of the nets showed that prediction of the drift paths of derelict fishing gear requires a detailed knowledge of the local surface currents and wind conditions. Recent Japanese studies of drifting gillnet (Mio et al. 1990) confirm these general findings; however, the ghost fishing characteristics of a lost, full length, pelagic driftnet (approximately 5 km) have yet to be measured.

Lastly, voluntary public beach cleanups have been organized to the extent that a uniform method of data collection is being employed in the western United States and Hawaii (Center for Environmental Education 1988). The data from these annual cleanup programs may have some utility as indices of the long-term changes in the amounts and types of beach debris in various regions. The myriad promoters of this voluntary initiative are intent on the development of a worldwide International Beach Cleanup Day using the same data collection methods. Over a 10-year period, the success of the implementation of MARPOL Annex V may be seen in the data from these extensive but infrequent (once or twice per year) samplings. They should be broadly promoted.

MITIGATION

Under this section, the collection of activities whose objective was to lessen the input of persistent debris into the ocean, and especially the North Pacific, are summarized. These actions include technical assessments and developments of waste handling and disposal technologies, as well as legal and administrative efforts. Recent progress in both categories affects most ocean areas, including the North Pacific.

Legal and Administrative Actions

On 30 December 1988, the terms of optional Annex V of the International Convention for the Prevention of Pollution from Ships as modified by the Protocol of 1978 (MARPOL 73/78) entitled "Regulation for the Prevention of Pollution by Garbage from Ships" entered into force for 35 nations representing slightly over 50% of the world's registered shipping tonnage. The MARPOL Annex V prohibits the discharge of plastic from ships into the ocean and sets distance-from-shore limitations for the discharge of other types of ship's garbage. Table 1 summarizes the discharge requirements of Annex V. Ships are defined under MARPOL 73/78 as all surface and subsurface craft as well as all fixed and floating platforms regardless of size. Annex V also identifies five special areas in which all discharge of garbage is prohibited. There are no special areas in the Pacific Ocean.

The principal North Pacific coastal nations that have ratified, and are implementing, MARPOL Annex V are North Korea, Japan, the U.S.S.R., and the United States. The domestic implementing legislation for Annex V differs somewhat between nations but, typically, flag vessels of signatory nations must meet the discharge requirements worldwide. All vessels within the EEZ's of signatory nations must meet the discharge requirements.

The Japanese showed concern over the trashing of the Pacific as early as 1970, when they enacted Domestic Law 136, "Law Relating to the Prevention of Marine Pollution and Maritime Disaster," which prohibits discharge of nets or net fragments and promotes onboard incineration. At the urging of the Fur Seal Commission in 1983, Japan joined the United States and the U.S.S.R. in a campaign to protect fur seals from entanglement by stopping the dumping of fishing gear and by cutting plastic strapping bands before discard. In June 1987, the Fisheries Agency, the Government of Japan (formerly the Fisheries Agency of Japan) established the Fishing Ground Preservation Division to carry out a broad range of projects related to the marine debris problem and its solutions. This program sponsors the research on the types and distribution of marine debris in the North Pacific reported above, and promotes a broad range of recycling, cleanups, and public education efforts, principally through prefectural governments and regional fishing organizations. Japanese domestic regulations implementing MARPOL Annex V were set in place in March 1988.

In response to the northern fur seal entanglement problem and the 1984 FIMD workshop, the United States set up the Marine Entanglement Research Program in the National Oceanic and Atmospheric Administration (NOAA). This program is charged with formulation and execution of research, mitigation, and education activities to address the marine debris problem in U.S. waters.

At the request of 30 U.S. Senators, and under the direction of the White House Domestic Policy Council (DPC), NOAA convened the Interagency Task Force on Persistent Marine Debris, which included the Departments of Defense, the Interior, Transportation, and Agriculture as well as the Environmental Protection Agency (EPA), the Office of Domestic Policy, the Marine Mammal Commission, the Office of Management and Budget, and the Office of the President. The Task Force reviewed the problem and produced a set of recommendations for United States actions. The DPC approved and published the Task Force Report in May 1988 (NOAA 1988). As implemented, these recommendations will have far-reaching impacts on the control of persistent marine debris in the North Pacific.

Table 1.--Summary of at-sea garbage disposal regulations. Source: Guidelines for the implementation of Annex V of MARPOL 73/78 (IMO 1988). (Note: The Baltic Sea special area disposal regulations took effect on 1 October 1989.)

	All ships except platforms[a]		
Types of refuse disposed	Outside special areas	Special areas[b]	Offshore platforms[a]
Plastics, including synthetic ropes and fishing nets and plastic garbage bags	Disposal prohibited	Disposal prohibited	Disposal prohibited
Floating dunnage, lining, and packing materials	Disposal permitted >25 nmi offshore	do	Do.
Paper, rags, glass, metal, bottles, crockery, and similar refuse	Disposal permitted >12 nmi offshore	do	Do.
All other garbage including paper, rags, and glass, comminuted or ground[c]	Disposal permitted >3 nmi offshore	do	Do.
Food waste not comminuted or ground	Disposal permitted >12 nmi offshore	Disposal permitted >12 nmi offshore	Do.
Food waste comminuted or ground	Disposal permitted >3 nmi offshore	Disposal permitted >12 nmi offshore	Disposal permitted >12 nmi offshore
Mixed refuse types	(d)	(d)	(d)

[a]Offshore platforms and associated ships include all fixed or floating platforms engaged in exploration or exploitation of seabed mineral resources, and all ships alongside or within 500 m of such platforms.

[b]Garbage disposal regulations for special areas shall take effect in accordance with Annex V 5(4)(b).

[c]Comminuted or ground refuse must be able to pass through a screen with mesh size no larger than 25 mm.

[d]When garbage is mixed with other harmful substances having different disposal or discharge requirements, the most stringent disposal requirements shall apply.

A wide range of activities have been undertaken in international organizations and commissions that recognize and address the marine debris issue. The broadest possible recognition of persistent marine debris as a legitimate marine pollutant has been a goal of the United States. As a result of actions by the United States, Japan, and others, the marine debris problem has appeared on the agendas of the International North Pacific Fisheries Commission, the International Fur Seal Commission, the Intergovernmental Oceanographic Commission, the Commission for the Conservation of Antarctic Marine Living Resources, the Food and Agriculture Organization, the United Nations Environmental Program, and, of course, the International Maritime Organization (IMO). One of the principal products of these international actions is the publication of guidelines by IMO (1988). The main objectives of these guidelines are:

- to assist governments in developing and enacting domestic laws which give force to, and implement, Annex V;
- to assist vessel operators in complying with requirements set forth in Annex V and domestic laws; and,
- to assist port and terminal operators in assessing the need for, and providing, adequate reception facilities for garbage generated on different types of ships.

All maritime nations are encouraged to ratify and implement Annex V, using the guidelines to help standardize international practice.

The provision of adequate port reception facilities to receive ships' garbage has been a significant concern expressed by port and terminal operators in the United States. Two projects were undertaken at North Pacific ports to evaluate this issue: one in the west coast fishing and logging port of Newport, Oregon, and one involving Unalaska/Dutch Harbor and Kodiak, Alaska. The Newport Marine Refuse Disposal Project found that community and port user involvement in, and ownership of, the local marine refuse problem led to a high level of usage of port reception facilities. Further, efficient waste management practice in the port was maintained by integrating the garbage reception system with recycling and reuse programs in the community and with waste oil reception sites. The lessons from the Newport Project are reported by Recht (1988). Currently, under a grant from NMFS the Pacific States Marine Fisheries Commission is conducting a program to assist eight west coast ports in their development and provision of adequate garbage reception facilities.

The results of the Unalaska/Dutch Harbor and Kodiak evaluations of port garbage handling problems were released in October 1989. Results suggest that the waste disposal facilities of these remote, highly vessel-dependent ports may be strained by the addition of vessel garbage. This is particularly true for Dutch Harbor, where the landfill life may be shortened significantly. These problems are complicated by the need to handle and dispose of waste oil, hazardous wastes, and garbage requiring special handling for pest control. Preliminary suggestions for solutions involve recycling, incineration, and regional consolidation of certain high-capital waste handling facilities. The experiences gained in this project and the Newport Project are generally applicable to ports all across the Pacific Rim.

The State of Washington has developed and published a Marine Plastic Debris Action Plan as a guide for state agencies in addressing the marine debris problem (Washington State Department of Natural Resources 1988). This plan is an excellent model for coastal states seeking guidance on organizing to deal with marine debris issues. California and Alaska are in the process of developing state policy and action plans.

The principal maritime nations of the North Pacific that have not ratified Annex V are Canada, Mexico, the People's Republic of China, the Republic of Korea, and Taiwan. Domestic laws of these nations addressing garbage discharge from ships have not been reviewed for this paper. It is known that the Canada Shipping Act provides the Canadian Government with the authority necessary to establish garbage regulations more stringent than Annex V. The Government of Canada is currently reviewing options for marine debris programs and controls. The Republic of Korea has developed a guide for the conservation of marine mammals and salmonids in the North Pacific which requires fishing vessels to retain, and return for shore disposal, all plastics and waste fishing gear, and to maintain a record of these actions. Legislative and policy actions on marine debris in other North Pacific countries have not been widely reported.

Mitigation Technology and Procedures

In general, efforts to develop or improve technology and procedures to reduce, control, or eliminate marine debris and solid waste have been carried out by private industry, by governments, and by independent organizations. This work covers shipboard-specific waste handling procedures and equipment, fishing gear technologies, incineration, recycling, and degradable materials. Little of the research and development in these areas has been specific to the North Pacific or to the marine debris problem. However, these developments are germane to controlling marine debris input to the North Pacific and are briefly discussed in this section.

Shipboard Waste Handling

Since the 1984 FIMD workshop no primary technology has emerged to control either ship-generated or land-source debris entering the oceans. The variety of applications and needs has operated to broaden, rather than narrow, the technical and procedural options open to all who must dispose of wastes. While regulatory systems seem to have progressively restricted disposal options on land, most regulators are allowing vessel operators to choose methods most suited to their circumstances. Absent any substantive reasons to the contrary, preserving all technical options that allow disposers to meet the requirements of the law should result in higher levels of compliance.

In 1986, NMFS contracted for a review of shipboard waste handling options. The report (Parker et al. 1987) produced a table showing the applicability of various waste disposal methods for various types of ships. Limited data on waste generation rates, ship configurations, and procedure capacities required some assumptions to be used in developing the table. The most general findings in this study were that:

- controlled incineration could be used aboard all but the smallest vessels;

- in using compactors, all but ships with very high crew complements (military vessels) should be able to store their compacted wastes on board;

- storage of uncompacted wastes on board is limited to fishing boats, research vessels, and others where the vessels are large relative to crew size; and

- waste generation rates on most vessels are too low to make recycling an economically attractive approach.

Alig et al. (1990) and Martinez (1990) review the more recent developments in shipboard waste handling technology and procedures.

The entry into force of Annex V has resulted in increased use of, and experimentation with, burn barrels for disposing of plastics and other garbage aboard ships with small crews, especially fishing boats in the North Pacific. The NMFS commissioned a study of the design and use of burn barrels to provide information on their technical feasibility, safety, and environmental considerations (SCS Engineers, Inc. 1989a). The work concludes that burn barrels are currently legal outside 12 nmi, may be regulated by coastal states inside 12 nmi, are not yet regulated by the EPA, are capable of reducing certain types of garbage to ash, and, under certain conditions, can be operated safely (Chang 1990). Operating and safety guidelines for the use of burn barrels aboard ships were prepared (SCS Engineers, Inc. 1989b). However, neither NMFS nor the contractor for these studies advocates the use of burn barrels.

Degradable Plastics

Since the 1984 FIMD workshop, the replacement of disposable plastics and fishing gear with degradable plastics has been widely discussed. This has been characterized as a potential solution for ghost-fishing problems caused by lost and discarded fishing gear, as well as a potential solution for litter and landfill capacity problems. Substantive research and development work on these types of plastics has been renewed after some initial work in the early 1970's. Most of this work is being done within the plastics industry and is proprietary. The American Society for Testing and Materials has formed a technical committee to define and develop standards for degradable plastics. In the mean time, there have been many commercial claims of product performance and applications for degradable polymers. Whether these products or future products will play a substantial role in controlling future plastic waste impacts on the environment remains to be seen.

The single recent study of the degradation properties of certain polymer types in marine and terrestrial settings was carried out by Andrady (1990). There has been no applied research on the use of degradable polymer products in the fishing industry. The primary work has been in the applications of natural fiber connectors or linkages in traps and pots to reduce their ghost-fishing life. Some coastal states around the North Pacific require natural fiber lacings or hangings in side panels or tunnels of crab, lobster, and fish traps. Ideally, these rot out shortly after the device is lost, rendering the trap harmless. A recently realized drawback to these approaches is that most natural fiber twines on the market are now fortified with some percentage of polymer fibers and do not rot as quickly or completely as expected (W. G. Gordon, New Jersey Marine Science Consortium, Sandy Hook: Executive Office, Building 22, Fort Hancock, New Jersey 07732, pers. commun. February 1988).

Fishing Gear Marking

Ghost fishing and entanglement are a widely recognized result of the loss and discard of fishing gear and gear fragments. The MARPOL Annex V explicitly excludes the accidental loss of fishing gear from its plastics discharge prohibition. This is sensible because, as a rule, fishermen balance the cost of replacing gear and the associated lost fishing opportunities against the expected value of their catch. Under most circumstances, this equation limits the risk of gear loss to economically acceptable levels. However, as long as fishing is a legitimate activity, some gear will continue to be lost. The wildlife and vessel hazards presented by this continuing accumulation will remain after all other plastic debris is controlled.

It has been suggested that the control of loss, discard, and abandonment of fishing gear could be improved through the use of marking systems. Nonremovable marks presumably could allow derelict gear to be traced back to its owner so punitive action could be considered. Thus, marking systems might add to fishermen's incentive to avoid loss, cease discard, and put more effort into recovery. The practical application of such marking systems would require a complex administration and a near-foolproof technology to succeed.

Under a grant from NMFS, a review of potential fishing gear tagging methods was conducted. The materials used in commercial fishing gear, their manufacturing and assembly techniques, and their working parameters were reviewed. Marking techniques considered were in the following categories: external tags, implants of various types, color codes, chemical codes, and bonded sheaths. This study (Northwest Marine Technology, Inc. 1989) concluded that it is technically feasible to mark fishing gear and that the optimum system will depend on the gear type. It points out that no matter what type of system is employed, extensive record keeping would be required if vessel-of-origin information is to be retained. This study did not evaluate the socioeconomic or political suitability of application of these techniques for any specific fishery or region.

It remains to be seen whether future improvements in fishing technology and procedures will actually reduce gear losses and increase recovery rates or merely enable greater risks to be taken. This issue will be given increased attention in the United States in coming years.

The Marine Plastic Pollution Research and Control Act of 1987 required NMFS to report on the utility of using bounty systems and incentive systems to control the loss and discard of fishing gear in the ocean. To address this question, NMFS funded a workshop on these subjects in February 1988 in Portland, Oregon. The workshop concluded that artificial mechanisms to control fishermen's compliance with the regulations implementing MARPOL Annex V would be premature (Alaska Sea Grant 1988). It was recommended that education programs be continued and that such consideration wait until the required reports of compliance are made by the U.S. Coast Guard. If compliance levels are unacceptable then regulatory mechanisms should be explored in consultation with the fishing industry.

Recycling

Efforts to recycle postconsumer plastics have met with a wide variety of successes in recent years. In general, the controlling factors in the economic viability of plastic recycling appear to be the volume, supply, and purity of feedstocks. With few exceptions, subsidies have been necessary to entice recyclers into the mixed, postconsumer plastics arena. The municipal waste streams of urban areas are rich in plastics but require labor-intensive sorting. Technology for automated, mixed-waste sorting is under development, but separating polymer types may not be feasible. In response to this realization, a number of processes and products for recycled mixed plastics have been and are being developed. Current product examples include substitutes for outdoor lumber, watering troughs for farms, and fillers for pillows, padding, and insulation.

Plastics recycling in Japan dates back to 1964. Nylon six gillnets have been actively recycled by melt reprocessing since 1974 (Matsunaga 1988). Products from the recycled nylon six gillnets include automotive and appliance parts, telephones, heels for shoes, golf tees, light structural reinforcements, and plastic reinforced glass products. In recent years, nylon 6 has been largely replaced by nylon 66 in North Pacific fisheries because it is thinner and stronger. Nylon 66 cannot be recycled because of its heterogeneous properties, and Japanese net recycling capacity exceeds the supply of nylon 6 (Matsunaga 1988). Fishing gear recycling is currently unprofitable and must be subsidized by Federal and local governments (Nakamura 1988). Research programs in the Fisheries Agency, the Government of Japan are exploring new processes for recycling fishing gear (Takehama 1988). Aizawa and Satou (1990) report on the disposition and recycling of plastic products including nets.

It is noteworthy that in both Japan and the United States there appears to be a considerable demand for used fishing nets for less demanding fishery applications as well as for nonfishery uses. These uses include shellfish culture, seaweed drying, garden uses, erosion control, sports goals and backstops, and decorations. It is encouraging that domestic demand may absorb at least some of the nonrecyclable gear while recycling and other disposal alternatives are developed. Ports accepting waste fishing gear under Annex V requirements should explore ways to encourage this demand.

MARINE DEBRIS EDUCATION

Recognizing that littering is chronic in developed and developing nations; that dumping at sea is a time-honored disposal method; that cheap, persistent plastics have changed the nature of the litter problem; and that terrestrial and marine enforcement capabilities are limited at best, realistic progress in the minimization of input of persistent wastes into the marine environment can only be brought about through gross changes in public attitudes and behavior. Education and example are repeatedly identified as the processes for effecting such changes.

Recognition of the ocean and coastlines as valuable national resources is particularly strong among the North Pacific Rim nations. Each of the cultures around the Pacific embodies an ocean ethos, the foundations of which lie in their maritime heritage. This heritage is based on resource utilization, trade, and transportation. A growing appreciation of the relationships between ocean (and environmental) health, productivity, and human use patterns appears to be making these cultural sentiments vulnerable to change. Education programs addressing the marine debris problem are intentionally or unintentionally using the broad appeal of the ocean and coasts to take advantage of this vulnerability. By moving a society's ocean ethos towards the belief that a clean ocean has value, individuals in that society will be less inclined to act counter to that belief.

The maritime heritage, hence the ocean ethos, varies widely among the cultures and subcultures around the North Pacific. To have a lasting effect on the attitudes and behaviors of a subculture (such as regional, ethnic, or industrial), education must be either so general that it does not seriously conflict with the world view or highly specific to that subculture's interests and vulnerabilities. In some cases, an education approach may fit both criteria. Marine debris education programs around the North Pacific have been combinations of both approaches.

Concern over entanglement of northern fur seals and ghost fishing by derelict gillnets in the North Pacific dictated that the first marine debris education program be focused on the fishing industries. In 1983, the North Pacific Fur Seal Commission funded the preparation and distribution of a poster requesting fishermen of Canada, Japan, the U.S.S.R., and the United States to control their discharge of net fragments and packing bands to reduce seal entanglement. Starting in 1985 in the United States, NMFS developed information, documents, and other educational materials for distribution to the fishing fleets of the Pacific Rim nations. Seminars and printed materials were given to every fishing association and fisheries management entity on the U.S. west coast. Formal presentations were made, and printed matter was distributed in Japan, the Republic of Korea, and Taiwan in 1986. Fishing industry associations independently and in conjunction with NMFS carried out marine debris awareness activities and developed and distributed information. The fishing industry sponsored a coast-wide meeting on the marine debris issue for fishermen in Newport, Oregon in July 1986.

The Newport meeting was followed by an international, industry-sponsored North Pacific Rim Fishermen's Conference on Marine Debris in Kailua-Kona, Hawaii, in October 1987. Sponsorship and participation in this conference came from fishing industry groups and associations from Canada, the Republic of China, Japan, the Republic of Korea, and the United States. The conference recommended a set of marine debris research priorities and adopted a resolution declaring the fishing industries' commitment to controlling their part of the marine debris problem. A group of fishing industry associations on the U.S. west coast used this resolution to develop an engraved plaque entitled "Fishermen's pledge for a clean ocean." The proceedings of this conference (Alverson and June 1988) are a valuable source of information about North Pacific marine debris programs and actions.

In response to all manner of inquiry from the public, NOAA established a west coast Marine Debris Information Office in San Francisco in late 1988. This office distributes 16 separate packages of general marine debris information depending on the nature of the request received. Requests for information may be mailed to:

Center for Marine Conservation
Marine Debris Information Office, NOAA
312 Sutter Street, Suite 606
San Francisco, CA 94108 U.S.A.

The broadest possible audience has been sought through the production of a variety of posters, brochures, and videotapes. An award winning 7 1/2-m video called "Trashing the oceans" was produced in 1987 and has been shown all over the world. This production is suitable for general audiences and is available from NOAA or the Marine Debris Information Offices. The NOAA, the Society of the Plastics Industry, and the Center for Marine Conservation (CMC) worked together to develop and distribute brochures and public service advertisements through marine trade journals and magazines nationwide (Bruner 1990; Debenham 1990).

Judie Neilson first organized large-scale, public, voluntary beach cleanups focusing on the persistent waste problem in Oregon in 1984 (Neilson 1985). The idea has caught on in every coastal state in the United States as well as in Japan. In 1988 in the United States, 47,500 volunteers cleaned 5,630 km (3,500 mi) of shoreline, removing almost 1,000 tons of trash. These data were collected by the volunteers and assembled, analyzed, and reported by CMC with support from Federal and private sources (CMC 1989). The results of the cleanups have been widely reported in local and national media, used in congressional testimony, and incorporated into ever-broadening education programs.

In an attempt to ensure the widest possible understanding of the requirements of MARPOL Annex V and to build the basis for compliance, NMFS has contracted for the development and implementation of a shipping and cruise lines industry education program (Wallace 1990). This activity is directed at all vessels and vessel operators plying U.S. waters, regardless of nationality. Products from this work will include model shipboard waste management plans, summaries of the U.S. regulations implementing MARPOL Annex V, and packets of information on the impacts of marine debris. Delivery of these materials will be through corporate offices, union offices, and associations of shipowners and officers.

Programs initiated by the Fisheries Agency, the Government of Japan in recent years have included fishing industry and public education components (Yagi and Otsuka 1990). Voluntary beach cleanups have been organized in the coastal prefectures. Seabed cleanups involving fishermen and divers are being carried out in ports and high-use coastal areas. In 1986, 3,959 km^2 in 25 separate areas were cleaned. Several general video presentations on the marine debris problem, on cleanups, and on the national marine debris program have been produced for wide national and international distribution.

The Republic of Korea has developed an education program and a set of regulations to control the discharge of waste fishing gear from its fishing vessels (Lim 1988). Each year, vessel captains are required to attend a training session by the National Fisheries Research and Development Agency which includes marine debris education. The admiral of the Korean Deep Sea Fisheries Association is charged with educating Korean fishermen against discharging entangling materials. The full extent of Korean and other Pacific Rim countries' marine debris education activities, apart from fishing industry actions, is unknown.

Finally, in an effort to raise the world level of understanding and appreciation of all facets of the marine debris problem, the NMFS initiated and acted as principal sponsor for the Second International Conference on Marine Debris.

CONCLUSIONS

The recommendations from the 1984 FIMD workshop have not been fully met. Research on the impacts of marine debris on wildlife has not established a clear understanding of the role of entanglement and ingestion in the population fluctuations of any marine species. Efforts to measure the sources and amounts of persistent debris have been greater in the North Pacific than in any other ocean area, but a full understanding of the dynamics of input, output, and circulation remains well in the future.

However, since the FIMD workshop, mitigation and education efforts have enjoyed the highest priorities. By international standards, legal and administrative actions to address the marine debris problem have progressed rapidly. The entry into force of MARPOL Annex V marks the primary international step in controlling ship-generated debris. Technological solutions for solid waste in the oceans and on land are now receiving major attention from government and industry sectors around the Pacific Rim. Education programs continue to expand, reaching people all over the world, even though the high level of international cooperation recommended by the FIMD workshop has not been achieved. As domestic policy and problems are addressed, the opportunity for, and suitability of, international action will increase.

Research

The research community addressing persistent waste pollution of the oceans is in a period of transition. Researchers, particularly biologists, initially noted the effects of marine debris as an oddity, not necessarily associated with their primary research. Since the FIMD workshop and the entry into force of MARPOL Annex V, the study and understanding of this type of pollution has become a legitimate, although minor, activity purposely incorporated into marine research agendas. As this evolution proceeds, definitions of terms are accepted, methods of inquiry are shared and generalized, new disciplines are involved, the literature is established, and the underpinnings of a new subdiscipline are solidified. The next 5 years will undoubtedly see the recognition of a marine faction of the solid waste research community including biologists, chemists, oceanographers, engineers, economists, lawyers, and possibly an institution or two. The work of this community is likely to be more applied than basic, as the immediate problems of solid waste management at sea and along the coasts must be solved to comply with current and future statutes. This emphasis will likely result in the diversion of limited resources from research on the biological impacts of marine debris.

While North Pacific species (northern fur seal, Hawaiian monk seal, Laysan albatross) have been the most intensively studied, inability to field pelagic research programs continues to prevent full elucidation of the role of debris in population changes. Increased knowledge of the behavioral and physical mechanisms of impact and the materials involved has strengthened the deductive evaluations of effects on populations, particularly for northern fur seals. Should international field research programs be developed for North Pacific high seas driftnet fisheries, information may become available to assess further the impacts of marine debris on fur seals. The experiments necessary to finally assess the physical impact of plastic ingestion on seabirds and sea turtles should be undertaken immediately. Studies on the possible toxic effects of plastic ingestion should also be initiated.

Specific regional studies of the direct and indirect costs to coastal communities resulting from debris are overdue. Collection of information on the incidence of vessel damage caused by persistent marine debris has been sporadic and mostly anecdotal. There have been few recent studies of the impacts of ghost fishing on target or nontarget species, on fisheries production, or on profitability. These types of information are essential for evaluating the range of economic impacts of debris and for crafting appropriate solutions. Clear, broadly applicable models for evaluating the economic impacts of accumulating marine debris would be valuable tools used worldwide.

Mitigation

Marine debris mitigation is proceeding apace. Laws are being passed, attitudes are changing, and industries are getting the message. The relationship between marine debris and the overall solid waste crisis is the real key here. The marine problem will not be completely solved until the land-based disposal problem is solved. Broad public concern for the ocean and coastal environment has allowed a start to be made; there can be no turning back. The timetable for control depends on the rate of development and implementation of rational solid waste disposal practice. For the near future, two areas of emphasis are evident. First, the remaining North Pacific Rim nations must accede to MARPOL and ratify Annex V. Second, the focus for the next several years must be on technology, policy, processes, regulation, enforcement, and education to fully implement MARPOL Annex V. On land, appropriate combinations of source reduction, recycling, incineration, substitution, and use of landfills must be sought. Within 2 to 5 years, control of persistent waste discharge into the ocean could be fully institutionalized around the North Pacific Rim. This endeavor assumes increased international cooperation in the provision of port reception facilities, in enforcement, and in promoting responsible waste management by all maritime nations.

Education

At least in the United States, the power of ocean issues to stir public action has been increasing for several decades. The marine debris issue has become a major rallying point for advocates and educators alike, catalyzing public awareness and action on an array of environmental issues. A high level of volunteerism is being achieved in public and industry education programs. Apparently, the United States and much of the developed world are ready to accept the responsibility for solving the marine debris problem. It is an issue whose time has come, one that may open the way for increased public insistence on, and acceptance of, a more responsible environmental policy.

Each nation must develop and effectively distribute information on its laws and regulations to implement MARPOL Annex V or its national equivalent. Timely, informed assistance in this implementation phase is critical to the long-term public acceptance of these requirements. All vessel operators and ports need this assistance. It should be noted that widely publicized examples of enforcement actions can be highly educational.

For the immediate future, existing education materials should be translated and adjusted as necessary for broad international use. The beach cleanup programs should be expanded to include all coastal nations. The cleanup data should be reported as widely as possible. Outlets for marine debris education materials should be established and publicized by all national and international agencies having environmental or maritime responsibilities. These are all low-cost, highly credible activities that should appeal to most governments and organizations. After all, who is willing to say, "I support marine debris?"

Finally, the Third International Conference on Marine Debris should be held in 1994 or 1995 to document world progress on this issue.

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OVERVIEW: MARINE DEBRIS IN THE NORTHWEST ATLANTIC OCEAN

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ABSTRACT

This review emphasizes recent developments (since the author's 1988 report) in regard to marine debris sources, types, amounts, and distribution, effects, and mitigation, on the Atlantic coasts of Canada and the United States.

INTRODUCTION

A substantial body of information about sources, types, amounts, and effects of marine debris exists for the northwest Atlantic Ocean, most of which is summarized in a report (Heneman 1988) distributed to participants at this conference. This presentation includes general observations based on that report but emphasizes new developments.

For our purposes, the northwest Atlantic reaches from the Atlantic coast east to midocean and south to, and including, the North Equatorial and Antilles Currents. Its western watershed, which includes the St. Lawrence and many lesser rivers, drains the most densely populated and industrialized areas of the United States and Canada.

SOURCES, TYPES, AMOUNTS, AND DISTRIBUTION

In contrast to areas of the world where a few sources account for most marine debris, the northwest Atlantic is plagued by a great variety of major debris sources. Merchant shipping, commercial fishing vessels, cruise ships, recreational boats, and naval vessels may be the largest sources, although MARPOL Annex V should cause these to diminish in importance. At the same time, inadequate storm drain and sewage treatment systems in the United States and Canada are known to dump large amounts of floatables into the marine environment, especially in periods of high rainfall; coastal landfills commonly "leak" debris into nearby waters; the plastics industry in the northeastern United States appears to have been a major source of plastic resin pellets; and beachgoers are an important source of litter. As we have seen with medical wastes for the past two summers, relatively small amounts of illegally dumped materials can have major effects. Virtually every kind of debris source that has been

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identified anywhere in the world is a contributor somewhere in the northwest Atlantic. This variety of major sources obviously complicates efforts to reduce amounts of marine debris and to mitigate its effects.

It is more difficult to generalize about where debris occurs in the northwest Atlantic than in a trade wind area such as the Caribbean. The North Atlantic gyre concentrates floating debris in the Sargasso Sea and on the beaches of Bermuda. Along the gyre's southern periphery, trade winds deposit large amounts of debris from the Antilles Current onto Atlantic-facing beaches in the Bahamas. Farther north, local sources and local wind and current conditions are more important factors influencing the distribution of debris on the United States and Canadian coasts.

There is little information on trends in amounts of marine debris. Wilber (pers. commun.) points out that his data and Carpenter and Smith's (1972) data for the northern Sargasso Sea indicate a 1,000% increase in the density of plastic pieces and a 200-400% increase in plastic pellets in a period of about 15 years.

There is little recent information to report from Canada on sources, amounts, and distribution of debris. Canada's Ocean Policy of 1987 includes commitments to deal with plastic debris and lost and abandoned fishing gear, but little has been done to implement the policy. Growing public concern may be leading to a change, however. Last summer, for example, the Nova Scotia Department of the Environment conducted one of Canada's first beach cleanups. An opinion survey at the same time found increasing indignation about litter on beaches.

EFFECTS

The best-known and most serious effects of marine debris along the northwest Atlantic coast are aesthetic and economic; the summer of 1988 provided another well-documented example of that when tourist-dependent coastal economies lost tens of millions of dollars to beach closures in the New York area. This is not a new problem, however; the first major incident of this sort was in the summer of 1976, when sewage and debris closed Long Island beaches and the Governor of New York declared a disaster.

Other effects, such as damage to vessels and harm to wildlife, are either minor or are poorly documented. At the Workshop on the Fate and Impact of Marine Debris (FIMD) in 1984, participants agreed that the effects of debris on sea turtles and of derelict nets and traps on fish and shellfish deserved greater attention (Shomura and Yoshida 1985). That is especially true for the northwest Atlantic, where these subjects may represent the most important information gaps.

ACTION AND MITIGATION

Two new programs in the United States are collecting information on types, sources, and amounts of debris. The Marine Entanglement Research Program and the U.S. National Park Service are sponsoring regular data collection at eight national seashores, including four on the Atlantic coast: Cape Cod, Assateague Island, Cape Hatteras, and Cape Canaveral.

The U.S. Environmental Protection Agency (EPA) has funded at least 1 year of a National Marine Debris Data Base, in which the Center for Marine Conservation is computerizing data from all the 1988 statewide volunteer beach cleanups. Over time, these two programs may provide a means of monitoring the success of Annex V and other mitigation measures.

On the Atlantic coast of the United States, mitigation efforts such as education and public awareness campaigns have focused on implementation of Annex V. The Marine Entanglement Research Program has funded several projects through the Center for Marine Conservation, including:

- a Marine Debris Information Office located in Washington, D.C. to respond to information requests from the Atlantic and Gulf coasts. It provides educational materials to marine user groups, industry, educators, policy makers, and the general public;

- separate public service advertisement campaigns aimed at the commercial fishing, shipping, and plastics industries, and recreational boaters and fishermen;

- a review of marine debris information for the general public, "A Citizen's Guide to Plastics in the Ocean."

The Society of the Plastics Industry helped fund the Citizen's Guide, public service announcements for television, and other marine debris educational materials produced by the Center for Marine Conservation.

Another Center for Marine Conservation project, this one in Florida and funded by the National Marine Fisheries Service Saltonstall-Kennedy program, endeavors to show that education is a cost-effective method of persuading commercial and recreational fishermen to comply with Annex V.

There have been continuing and expanding efforts to remove debris from the marine environment. For instance, most coastal states have had annual beach cleanups in recent years. The Army Corps of Engineers, the EPA, the U.S. Coast Guard, and New York and New Jersey state agencies recently announced that they have begun a cooperative program in the New York area. They will try to locate concentrations of floating debris by helicopter and use Army Corps vessels to collect it.

Canada's Department of Fisheries and Oceans convened a workshop in Halifax, Nova Scotia, 17-18 May 1989. The workshop provided an opportunity for organizations and individuals from the private sector to advise the government on the development of an action plan on marine debris (Buxton 1989; DPA 1989).

As for mitigation efforts, Canada has placed itself in an unusual position. Although Canada is a signatory to the London Dumping Convention, it is not a signatory to MARPOL, much less to Annex V. For some years, the Canada Shipping Act has prohibited the disposal of any garbage or trash from vessels within 200 nmi of Canada's Atlantic and Pacific coasts, a provision that is stricter than Annex V. Unlike Annex V, however, the act does not restrict ocean disposal by Canadian vessels beyond 200 nmi, and it does not require ports to provide reception facilities.

Recent amendments to the Canada Shipping Act take a half step forward by *permitting* Canadian agencies to impose stricter regulations that would bring Canada into conformity with Annex V. But the agencies have not yet decided to actually adopt any new restrictions. Furthermore, there seems to be little enforcement of existing regulations and no educational programs to encourage compliance.

CONCLUSION

Although the Atlantic coast of the United States has the same marine debris problems, more or less, as other coastal areas of the country and the world, its problems receive more attention than is warranted simply by its geography. United States policy makers are concentrated in Washington, D.C. National, and to some extent international, opinion shapers are concentrated in New York City. As a result, events in that part of the world become more important.

To mention two examples: The cover story in Time magazine for 1 August 1988 is titled "Our Filthy Seas." That same week, Newsweek's cover story was "Don't Go Near the Water--Our Polluted Oceans." An issue has truly arrived on the national agenda when it makes the covers of these two magazines the same week, when it is a regular fixture on network news, and when it is an issue in a presidential campaign, as it was in 1988. The fact is, the response to marine debris problems on the Atlantic coast will continue to have a disproportionate influence on how the rest of the United States responds to its marine debris problems.

It has become abundantly clear since the 1984 FIMD workshop that the ultimate solutions to marine debris problems on the U.S. Atlantic coast are inextricably bound to solutions to the impending crisis in solid waste disposal on land. All of the elements that can contribute to reducing amounts and effects of marine debris--source reduction, recycling, degradability, changing societal attitudes towards waste--are vital in the larger arena of land disposal. That fact should inform much of our effort in regard to the marine debris subset of the problem.

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PLASTICS: ACCUMULATION, DISTRIBUTION, AND ENVIRONMENTAL EFFECTS OF MESO-, MACRO-, AND MEGALITTER IN SURFACE WATERS AND ON SHORES OF THE SOUTHWEST PACIFIC

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ABSTRACT

Plastic debris of all kinds and in all sizes is widespread in the southwest Pacific. Densities of virgin nibs exceed 1,000 km^{-2} in surface waters north of New Zealand and in nearshore waters adjacent to manufacturing centers. There is a latitudinal gradient of densities, with numbers falling to less than 20 km^{-2} south of New Zealand. On shorelines, greatest numbers (>>100,000 m^{-1} of beach length) are found near large cities, although a similar latitudinal gradient shows with very low numbers from around southern New Zealand (1-5 m^{-1}) and none from the subantarctic islands. In general, numbers of nibs on shores of eastern Australia are much less than they are on New Zealand shores. Significant numbers (>1,000 m^{-1}) have been found as local concentrations on some trade wind-facing beaches of all Pacific islands so far examined.

Distribution of these nibs, together with that of other plastic and persistent synthetic litter, is influenced by surface current patterns and prevailing wind regimes, with greatest concentrations being noted on windward and downdrift shores, in windrows, and (tentatively) along oceanic fronts.

Larger, fabricated plastic items have been seen on the shores of all isolated and unpopulated islands so far visited around the region. Where identifiable, sources frequently lie in distant water fishing activities. On populated islands, many of which lack adequate facilities for domestic waste and garbage disposal, there is a buildup of locally sourced litter along shores. Not only is this litter aesthetically distasteful, some materials (e.g., syringes) are hygienically unacceptable. The problem is an ever-growing one and needs addressing in appropriate forums. The environmental implications of this plastic pollution are many, with the most important involving entanglement and ingestion. The longer term significance of hazardous and persistent chemical residues, originally present in plastics as additives and released in minor amounts during degradation,

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is difficult to assess. Pelagic plastics also provide an important hard substrate for an encrusting biota that includes a hermatypic coral, bryozoans, coralline and filamentous algae, hydroids, barnacles, and some foraminifers, and are a largely unrecognized vector in their wider distribution.

From surface crazing and other evidence of aging such as chalkiness and embrittlement, it is inferred that degradation rates decrease progressively from lower to higher latitudes.

INTRODUCTION

It is generally accepted that surface waters of the South Pacific Ocean (Fig. 1) are relatively free from man-made pollutants, other than in the nearshore zone of more heavily populated islands (Matos 1981). Recent reviews have tended to emphasize localized incidents involving point-sources of sewage and industrial effluents (e.g., Suva Harbor, Fiji: Brodie and Morrison 1984), and toxic chemicals and pesticides (Cook Islands: Hambuechen 1973; and Tonga: Brodie and Morrison 1984; Morrison and Brodie 1985), although wider political concern has been expressed over the prospect of seabed disposal and dumping or storage of nuclear waste in the expanses of the region (Branch 1984; Carew-Reid 1988). The area lies remote from tanker routes (Waldichuk 1977) and major shipping lanes, and pelagic tar balls so common to more frequently traversed waters are rarely encountered (Butler et al., 1973, p. 24; Bourne 1976; Gregory 1977, unpubl. data; Oostdam 1984; Lee pers. commun.). The problems of marine oil pollution become more evident passing westward into southeast Asian waters (Bilal 1985). However, the island countries of the southwest Pacific have a long and commonly expressed concern over contingency planning for pollution from oil spills (Hayes 1981; Dahl and Baumgart 1983; Hayes and Kay 1986).

Plastics and other persistent synthetic materials are today a significant contaminant of both open ocean and nearshore waters, particularly those adjacent to the industrial North. The sources and environmental problems they create are many and varied (Gregory 1978, 1983; Laist 1987; Pruter 1987). Plastic artifacts as well as casual litter and solid domestic wastes have long been an acknowledged, although seldom seriously addressed, problem on several Pacific islands (Anonymous 1976; Connor 1976; Efi 1976). On Tonga, for example, plastics and cigarette and candy wrappers have been identified as ". . .the second most common form of litter and the second largest waste item for disposal" (Chesher 1984, p. 38). In all instances known to this author, the importance of local sources has been noted, with little recognition that some material may have been adrift for a time before stranding. The observations of Sachet (1955) on the wide dispersal of exotic pumice on Pacific atolls, as well as those of Bligh (1792) on coconut husks, are evidence that, over the vastness of the Pacific, floating materials can drift far from their places of origin. Drift pumice, often with an encrusting biota, is common on beaches of eastern Australia (Table 1). Similarly, in the Southern Ocean there is evidence of floating debris such as logs, pumice, and man-made artifacts being rapidly dispersed in circumpolar fashion by the strong West Wind

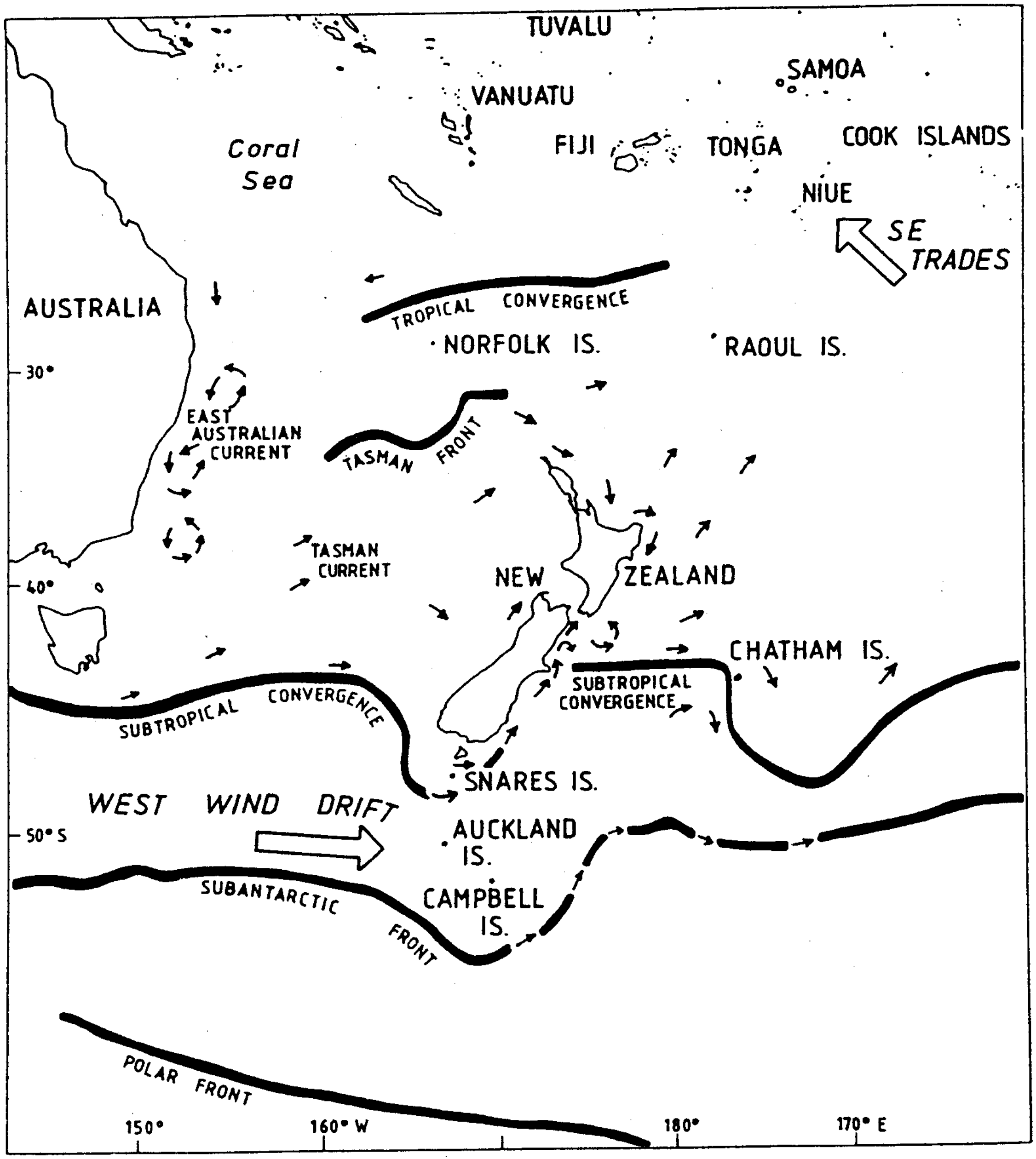


Figure 1.--Map of the southwest Pacific Ocean indicating principal places mentioned in text. Major oceanic features are also illustrated.

Drift Current and general oceanic circulation patterns (Barber et al. 1959; Gregory et al. 1984; Smith 1985; Gregory 1987, 1990; Lutjeharms et al. 1988).

Waters around New Zealand and its offshore islands are by any criteria relatively unpolluted, although semienclosed estuaries and harbors in the vicinity of larger urban centers give increasing cause for concern (Ridgway and Glasby 1984). Plastics and other persistent synthetic compounds,

Table 1.--Numbers of virgin plastic granules and drift pumice on selected beaches of eastern Australia (arranged from north to south). The quantities of granules are local maximums expressed in number per linear meter of shore, following the approach of Gregory (1978); p = present in low numbers ($<1\ m^{-1}$). Drift pumice: * = abundant, + = present.

Location	Plastic granules	Drift pumice
Tasmania		
Hobart to Bicheno	nil	nil
Victoria		
Portsea, Sorrento, Rosebud	p	nil
Mordialbo	>1,000	nil
St. Kilda	>500	nil
Altona	100	nil
New South Wales		
Narooma	nil	+
Batemans Bay	nil	*
Kioloa	nil	*
Jervois Bay	p	nil
Shoalhaven	>5	*
Stanwell Park	>50	*
Botany Bay	>>2,000	+
Bondi	>10	+
Manly	p	nil
Narrabeen	>20	nil
Port Macquarrie	p	*
Coffs Harbor	nil	*
Queensland		
Gold Coast	p	*
Brisbane (Red Cliffs)	nil	+
Bargara (Bundaberg)	5	*
Keppel Sands (Rockhampton)	5	*
Sarina	nil	*
Mackay	p	*
Townsville	nil	*

particularly those arising from packaging, are a significantly visible but minor part of the local waste stream (Ministry for the Environment 1987; Plastics Institute of New Zealand 1988). The environmental hazards and threats to local wildlife are varied and have been reviewed by a number of authors (Gregory 1977, 1978, 1987, 1990; Gregory et al. 1984; Cawthorn 1985, 1987; Mattlin and Cawthorn 1986; Dawson and Slooten 1987; Murray 1988).

Gregory (1977, 1978) initially recorded small virgin plastic resin granules and pellets in surprisingly high quantities on the New Zealand coast and mapped their distribution (Fig. 2). It was noted that greatest numbers occurred near metropolitan centers, suggesting that the distribution was caused by dispersal from local sources (Fig. 2), although some evidence indicated possible drift from eastern Australia waters (Gregory 1978). Changes in the composition of litter stranding on a remote northern New Zealand beach over an 8-year period have been recorded by Hayward (1984). Ever-increasing fishing activities add further to the seaborne litter load on even the most isolated shores (e.g., Auckland and Campbell Islands, Cawthorn 1985; Gregory 1987, 1990).

This paper reviews in detail the nature, characteristics, quantities, distribution and sources of pelagic plastics around the southwest Pacific region. It is based largely on the author's published studies from New Zealand and its offshore, subantarctic islands. However, the opportunity has been taken to include a corpus of previously unpublished data gathered from eastern Australia, several Pacific islands, and adjacent waters during opportunistic surveys over a number of years. The environmental consequences of this plastics pollution are evaluated and some conclusions reached on how they could be addressed.

PLASTIC MESOLITTER

In the category of plastic mesolitter I include the small, ovoidal-to-rounded and rod-shaped virgin plastic granules or nibs of polyethylene and polystyrene resins that are the raw materials or feedstock of plastic fabricators worldwide. The granules are mostly <5 mm across, are colorless to translucent or transparent, and have been described in detail previously (Gregory 1978, 1983). Intensely colored dye-carrying granules (yellow, blue, green, red, black, white) are never as common as the colorless ones. In addition, there are occasional sharply angular and jagged plastic chips of comparable size produced through granulation of larger items for recycling. These chips are variously colored but rarely transparent or translucent. Small, often flaky, fragments coming from the degradation and disintegration of larger plastic objects also fall into this category. The fragmenting and fracturing processes appear to be mostly embrittlement through oxidative aging and photodegradation rather than physical or mechanical weathering.

Gregory (1977, 1978) described the distribution of virgin plastic granules on New Zealand shores (Fig. 2). Large numbers, often >10,000 m^{-1} of beach length and in one instance >>100,000 m^{-1}, were recorded near some of the larger metropolitan and industrial areas where plastics fabricators are located (Fig. 2). Away from these regions numbers decreased, but they were persistently and surprisingly high at some remote localities (e.g., to >150 m^{-1} near North Cape; and to 50 m^{-1} near East Cape). Only around the southernmost part of South Island were they consistently very rare or absent. For the mid-1970's it was estimated that at least 1,000 metric tons of these granules were stranded on the shores of New Zealand (Gregory 1978).

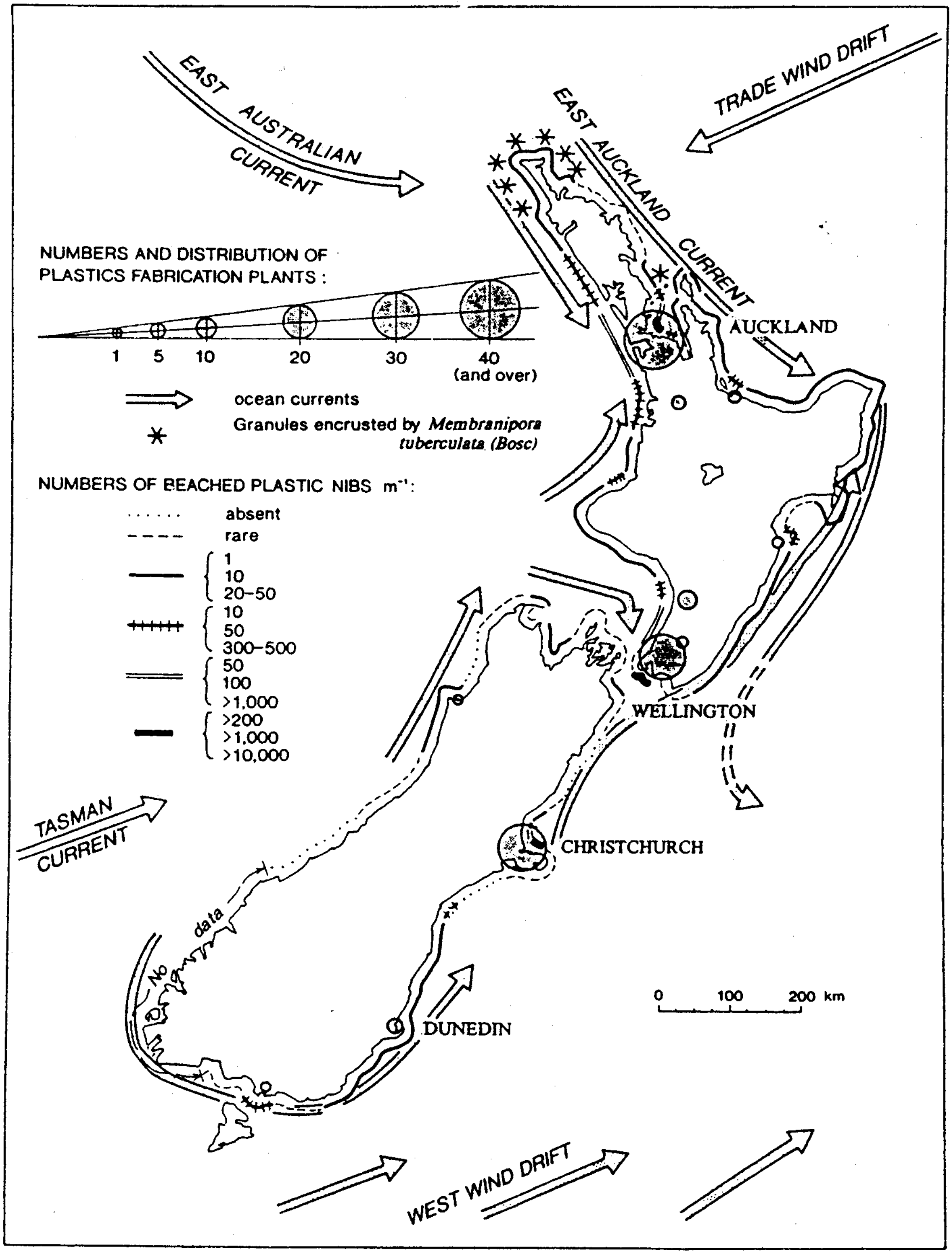


Figure 2.--Distribution of virgin plastic granules on New Zealand shores based on a 1972-78 survey. Three values given for each distribution line indicate abundance levels at which pellets were (i) reasonably consistent (lowest value, top of list), (ii) commonly encountered (middle value), and (iii) locally concentrated (greatest value). Data are from Gregory (1978). Local New Zealand sources of virgin plastic granules are after Bullen (1968); the surface currents and prevailing winds that spread them around and along the coast are after Brodie (1960).

Virgin plastic granules have been encountered on the shores of eastern Australia from Batemans Bay in New South Wales north to Townsville in Queensland (Table 1). They are also present around Melbourne and Adelaide. None have been noted on eastern Tasmanian shores northward from Hobart. Occurrences are sporadic, and numbers seldom reach those recorded from New Zealand. On remote beaches numbers are generally <1 m^{-1}, and in many instances a lengthy search is required to turn up any granules at all. It is only at a few isolated localities around Sydney (>2,000 m^{-1}) and Melbourne (>1,000 m^{-1}) that quantities ever approach those frequently recorded near Auckland.

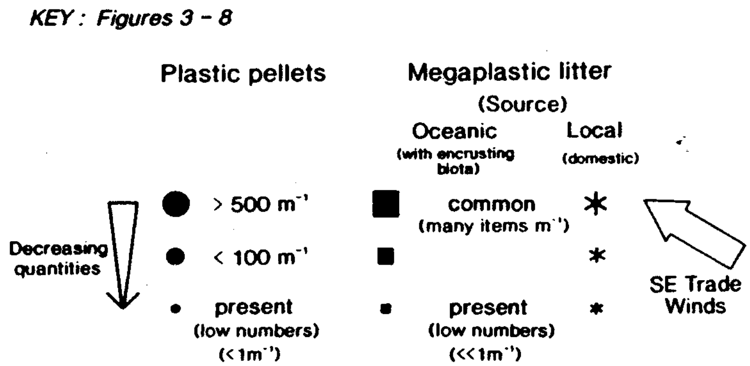
No virgin plastic granules have been found so far on any of New Zealand's subantarctic islands (e.g., Campbell, Auckland, Snares, Antipodes, and Bounty) (Gregory 1987), although they are not uncommon on Chatham Island (to >100 m^{-1}, Gregory 1978). The granules, however, have been found on all subtropical and tropical southwest Pacific islands that were systematically searched by this author during visits over the past few years (Table 2, Figs. 3-8). In several instances the numbers are unexpectedly high for such remote, nonindustrialized places (e.g., Tonga, >>1,000 m^{-1}).

The angular granules produced for recycling are never common away from the industrial centers of Australia and New Zealand, and have not been encountered on the shores of those Pacific islands so far examined.

The numbers of plastic granules and larger plastic items afloat in surface waters of the New Zealand sector of the Southern Ocean have been determined from over 50 neuston tow stations (Gregory et al. 1984; Gregory 1987, 1990). The numerous reports of Southern Ocean feeding seabirds ingesting plastic granules and other artifacts (Bourne and Imber 1982; Furness 1983; Randall et al. 1983; Brown et al. 1986; Skira 1986; Gregory 1987, 1990; Harper and Fowler 1987; Ryan 1987a) indicate these materials have circumpolar dispersal. Brief and sporadic surveys of pelagic plastic have been undertaken from research vessels on passage between New Plymouth and Norfolk Island, Tauranga and Raoul Island, and the Hauraki Gulf to Wellington by way of East Cape as well as around Auckland Harbor and its approaches. At this time data are inadequate to draw unequivocal conclusions. The data strongly suggest, however, that densities in surface waters to the north of New Zealand probably (and often substantially) exceed 1,000 km^{-2} (Fig. 9). Indeed, fresh granules stranding along the most recent swash line (by inference over one tidal cycle--February 1988) on Raoul Island at 5-10 m^{-1} suggest that densities approaching 10,000 km^{-2} may occur sporadically! Variation in numbers between stations is very large. There is apparently a strong latitudinal gradient in the areal density of floating granules (Fig. 9). In higher latitudes between the Subtropical Convergence and the Subantarctic Front, granules occur in numbers that may barely reach 20 km^{-2} (Gregory et al. 1984; Gregory 1987, 1990). Densities farther south and in the region of seasonal pack ice are negligible. In some nearshore waters much higher densities are commonplace (e.g., >10,000 km^{-2} in Hauraki Gulf; >20,000 km^{-2} in Auckland Harbor; >40,000 km^{-2} in Cook Strait approaches to Wellington Harbor) (Gregory 1990, unpubl. data). For comparison, densities elsewhere have been 1,500-3,600 km^{-2} for the Cape Basin region of the South Atlantic lying west of southern Africa (Morris 1980), and 3,640 km^{-2} from over 1,000 neuston trawl stations

Table 2.--Virgin plastic granule numbers on representative southwest Pacific island shores. Numbers given are local maximums expressed in number per linear meter of shore, following Gregory (1978); p = present in low numbers ($<1\ m^{-1}$). For locations see Figures 3-8.

Location	Number
Norfolk Island	
Emily Bay	ca. 100
Raoul Island	
North Beach	>50
Denham Bay	nil
Fiji, Viti Levu	
Lautoka	p
Singatoka	p
Korolevu	<5
Deuba	>>100
Suva	>5(?)
Fiji, Vanua Mbalavu	
East	24
West	p
Tonga, Tongatapu	
Anahulu Beach	100
Laulea Beach	>>1,000
Oholei Beach	<50
Keleti Beach	nil
Fahina Beach	nil
Western Samoa, Upolu Island	
Apia	p
Vaiala Beach	nil
Malaeia Beach	20(?)
Cook Islands, Rarotonga	
Ngatangiia Harbor	>500
Raringaru Stream	>>10
Akapuao Stream	<10(?)
Totokoitu Stream	p
Papua Stream	10
Rarotongan Hotel	1-<10



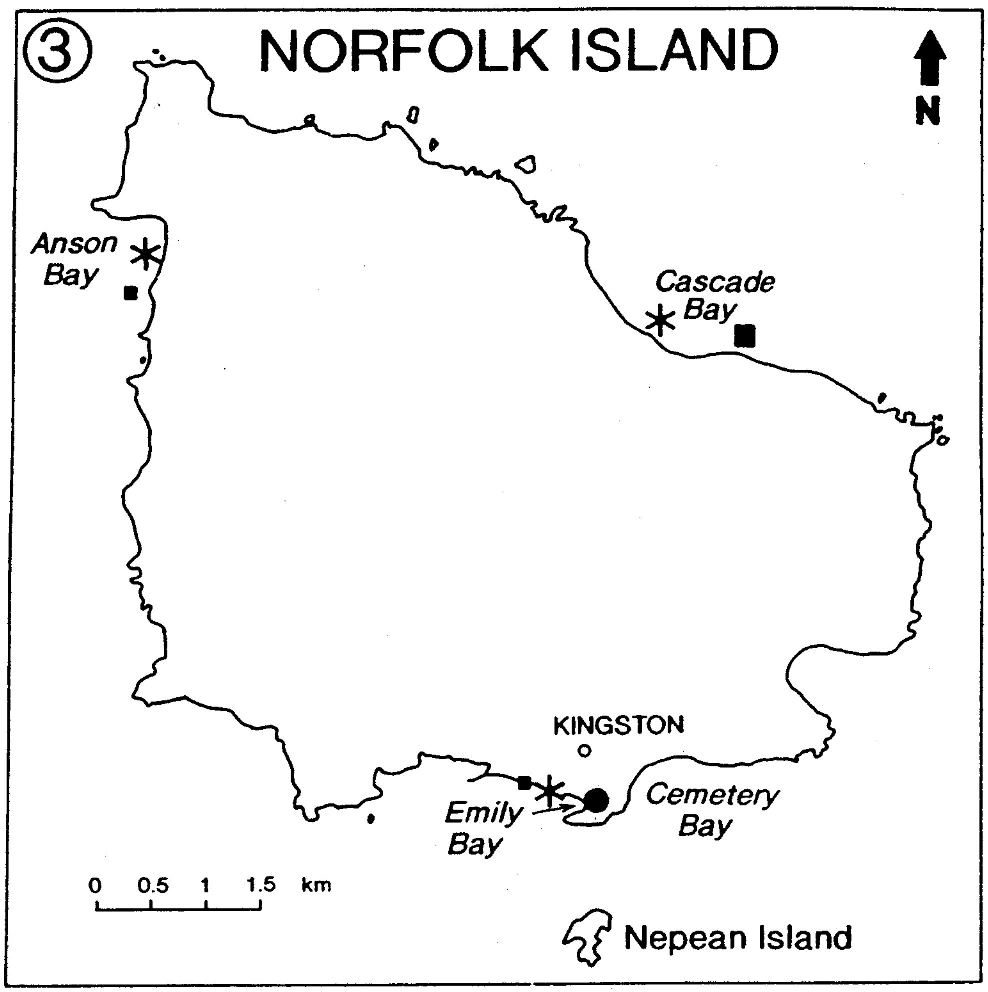
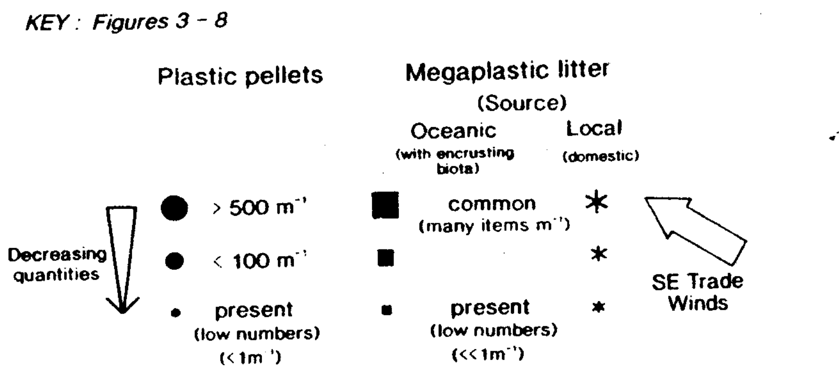


Figure 3.--Virgin plastic granules, oceanic and locally generated megalitter on southwest Pacific island shores: Norfolk.



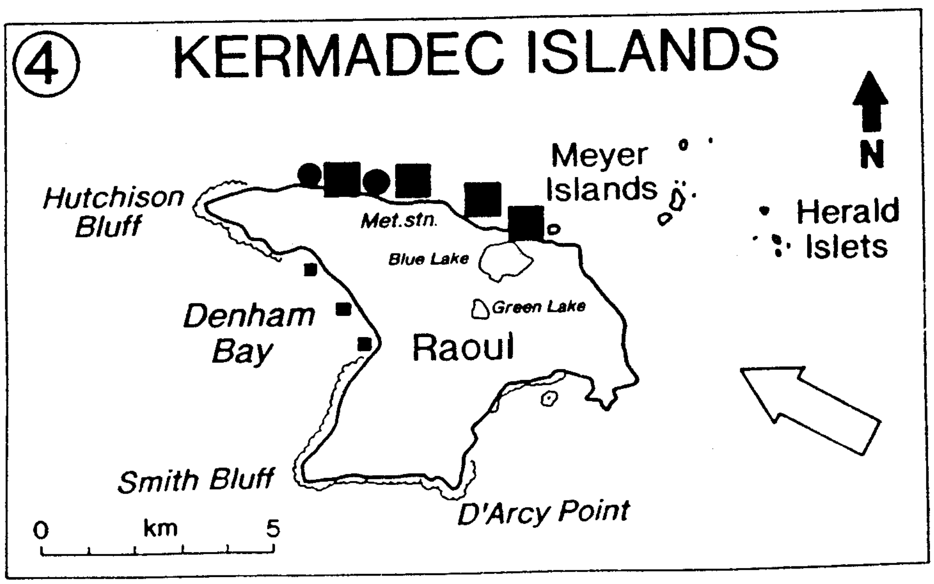
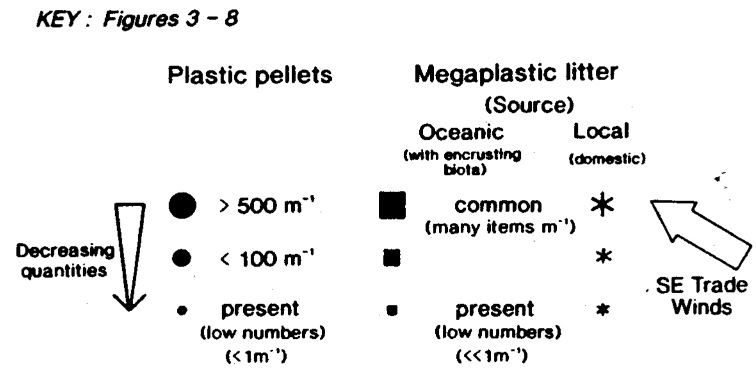


Figure 4.--Virgin plastic granules, oceanic and locally generated megalitter on southwest Pacific island shores: Raoul.



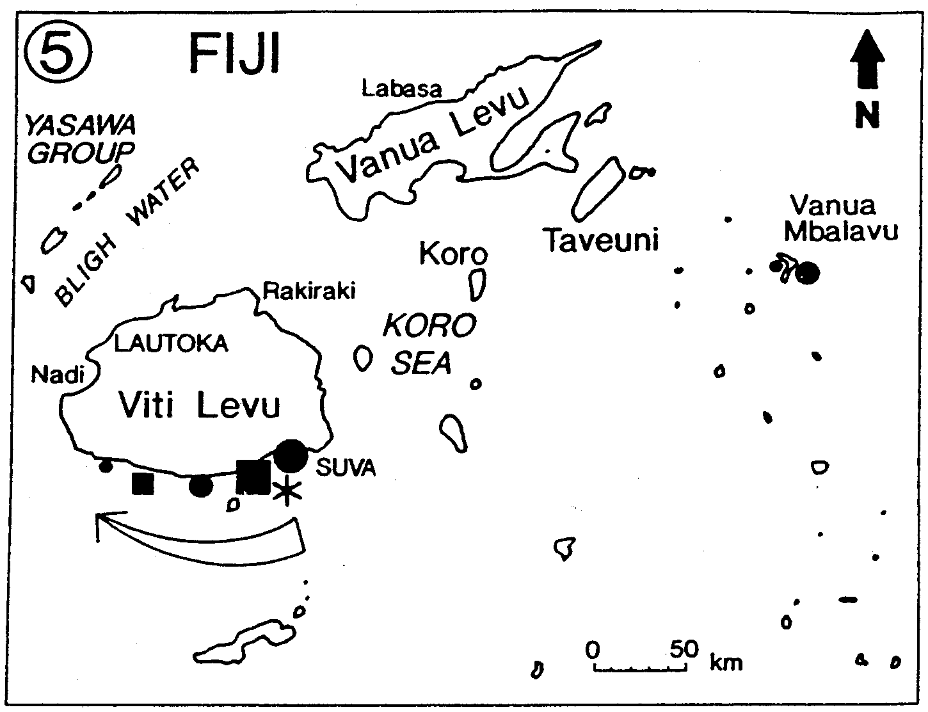
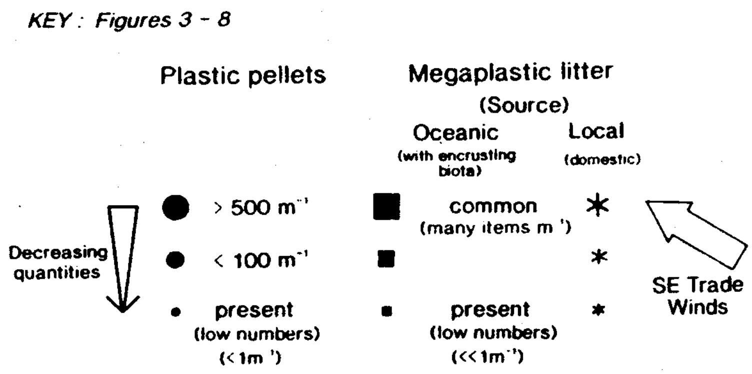


Figure 5.--Virgin plastic granules, oceanic and locally generated megalitter on southwest Pacific island shores: Fiji.



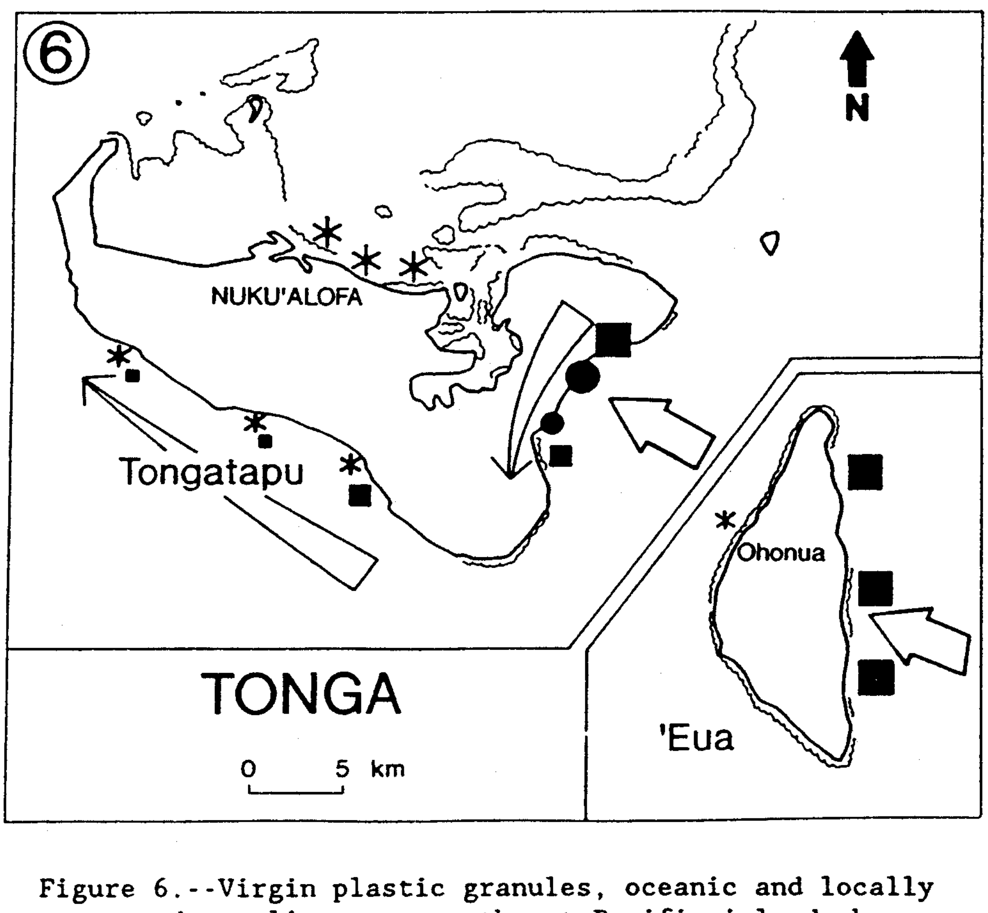
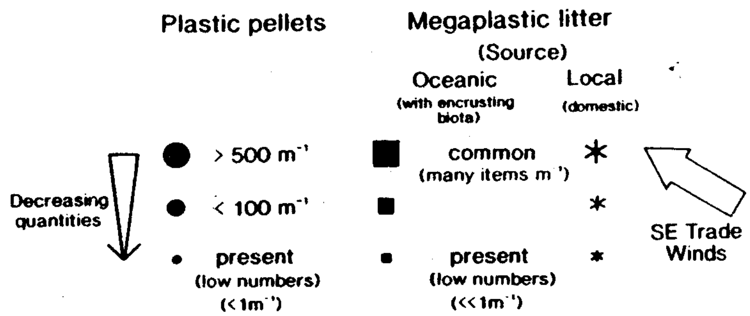


Figure 6.--Virgin plastic granules, oceanic and locally generated megalitter on southwest Pacific island shores: Tonga.

KEY : Figures 3 - 8



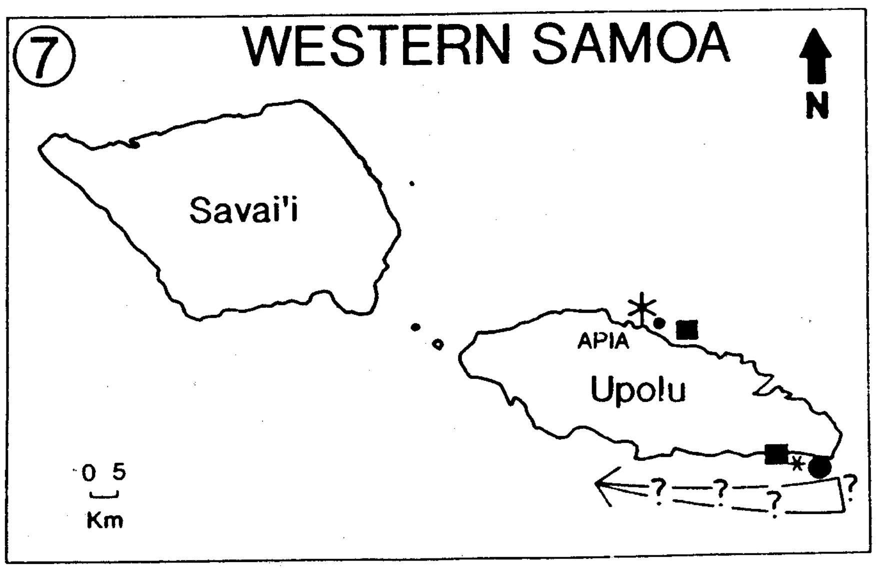


Figure 7.--Virgin plastic granules, oceanic and locally generated megalitter on southwest Pacific island shores: Western Samoa.

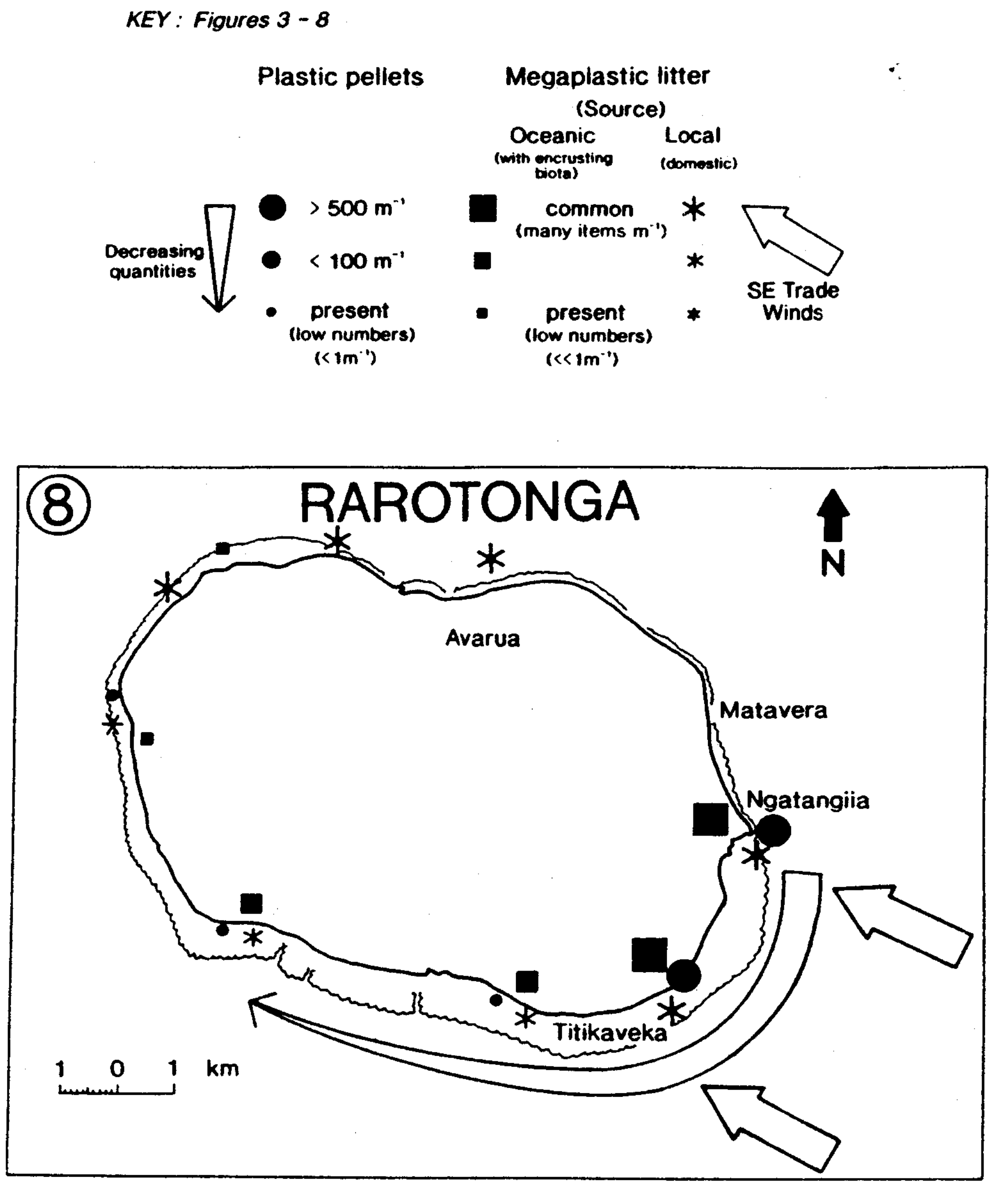


Figure 8.--Virgin plastic granules, oceanic and locally generated megalitter on southwest Pacific island shores: Rarotonga.

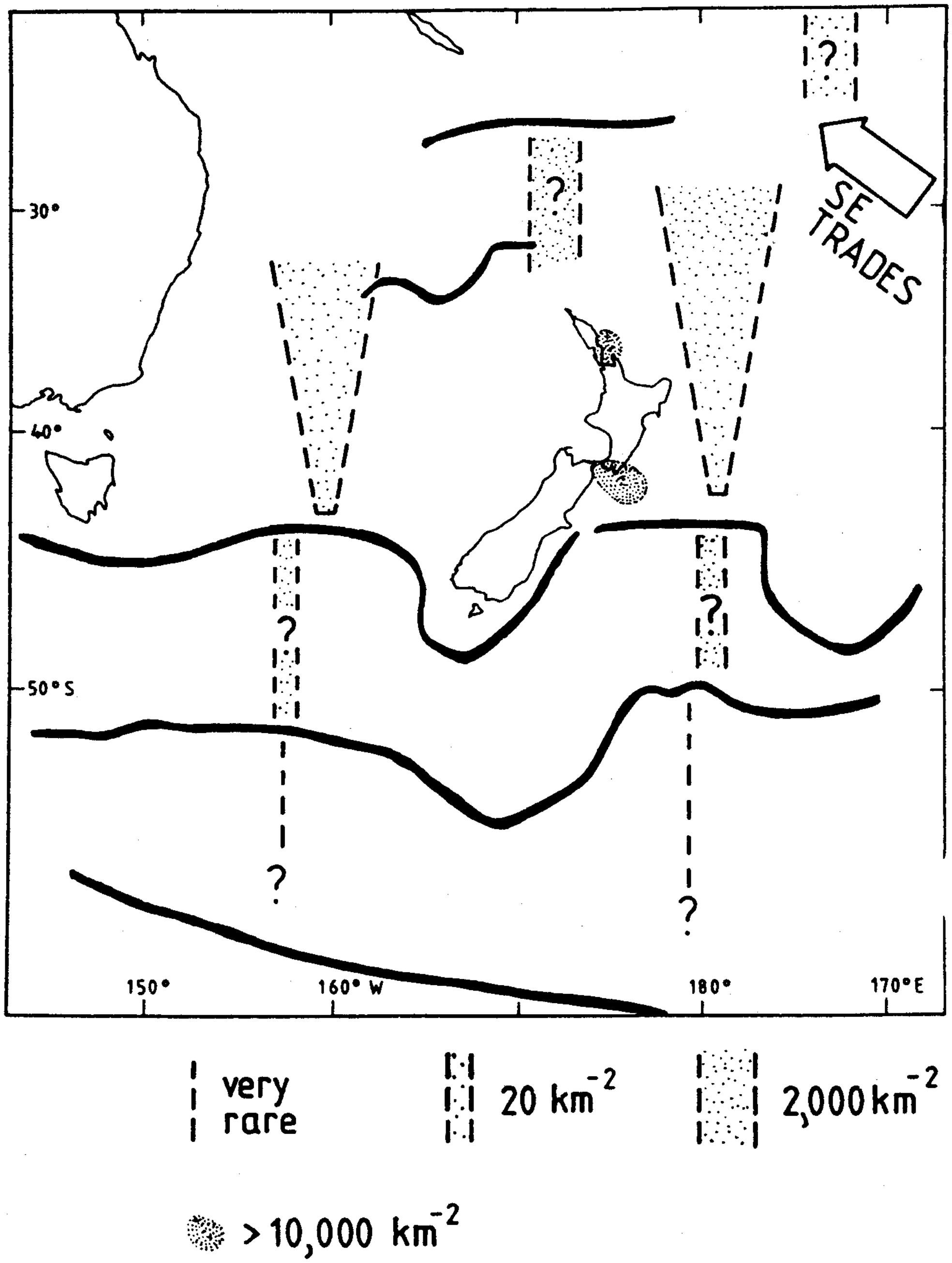


Figure 9.--Regional distribution of pelagic plastic granules across the southwest Pacific is influenced by oceanic fronts and wind and surface current patterns. Based on Gregory et al. (1984); Gregory (1987, 1990), and unpublished data.

for waters in the Agulhas Current up to 100 nmi offshore from Cape Province (Ryan 1988). On the other hand, densities in surface waters of the northern Sargasso Sea include >10,000 pieces of plastic and 1,500 pellets km^{-2} (Wilber 1987). Elsewhere around the eastern North Atlantic, densities of polluting plastic are lower, with only 700 pieces km^{-2} and 80 pellets km^{-2} being reported from waters north of the Gulf Stream (Wilber 1987).

PLASTIC MACRO- AND MEGALITTER

In the categories of plastic macro- and megalitter I include large manufactured items and artifacts fabricated from plastics and other persistent synthetic materials and the products of their fragmentation and disintegration, following the approach of McCoy (1988). Megalitter is of a size enabling visual identification of floating items by a shipboard observer (generally decimeters or larger), while macrolitter is mostly smaller items and fragmented material, larger than the previously described granules and readily seen with the naked eye during shoreline surveys. Typical examples of the former are fishing floats, containers, crates, bottles and their tops, netting, lines, hawsers, strapping bands, plastic sheeting and bags, foamed items, and confectionery wrappings. Only some of these items are readily degradable.

Significant quantities of macro- and megalitter have been seen on all shores examined to date (Tables 2 and 3, Figs. 3-8, 10-13). The amounts are highly variable, but even on uninhabited islands and the otherwise remotest of places discarded plastic is present. In a survey of New Zealand's subantarctic islands, Gregory (1987, Appendix 1) itemized a great diversity of plastic material and noted that the quantity of macrolitter was surprisingly small considering the abundance of megalitter items (Fig. 10). A similar diversity of seaborne megalitter becomes stranded on islands of the southwest Pacific. As an example, Raoul Island in the Kermadec Group some 500 km northeast of New Zealand (Fig. 1), has <10 permanent residents at a weather station, and yet large quantities of macro- and megalitter are stranded on the beaches (Table 3).

In late 1988 New Zealand's Department of Conservation, with cooperation from the Wildtrack Programme produced by the Natural History Unit of TVNZ (Television New Zealand), initiated a nationwide survey of plastic litter on beaches. Most participants are students who complete a standard record card (Fig. 14). Preliminary reviews of some 50 returns coming from widely separated places, both remote and near population centers of the North and South Islands, confirm casual observations that considerable quantities of plastic macro- and megalitter accumulate on these shores. It is surprising to note that few returns identified the small resin granules, even at places where they are reasonably common. Those items most frequently recorded were fragments of foamed and hard plastic, plastic bags and sheeting, strapping bands, bottles, and bottle tops. The following selected examples illustrate the magnitude of contamination:

74 bottles on 860 m of beach--Ohope, Bay of Plenty

426 bottles and 82 bags on 2 km of beach--Mohaka, Hawkes Bay

32 bags on 500 m of beach--Petone, Wellington Harbor

2,817 bottle tops (from repeated surveys: 4 August, 14 and 19 September 1988)--Oreti, Southland

200 packing straps on <200 m of beach--Mokomoko Inlet, Southland

Table 3.--Simplified catalogue of plastic megalitter and other artifacts found on a 3-km stretch of beach on the northern coast of Raoul Island, southwest Pacific.

Type of litter	Number
Fish boxes and crates	10
Fishery floats	26
Bottles and containers (detergent, cosmetics, etc).	40
Hawser, rope	
Long (ca. ±10 m)	10
Short (<10 m)	5
Netting (trawl) and rigid mesh	5
Foamed material (Styrofoam)	
Small (<2 cm)	>30
Moderate (>2 to <15 cm)	>10
Large (>15 cm)	>20
Sheeting	10
Strapping bands	>20
Footware (jandals/thongs)	20
Miscellaneous	>10

Repeated surveys (1974, 1978, 1981, and 1982) at Kawerua, a remote beach on the exposed west coast of Northland, showed a gradual decrease in numbers of plastic bags and an increase in bottles and total plastic items, probably reflecting changes in types of packaging over that period (Hayward 1984). Comparable trends in plastic megalitter accompanying changing patterns in offshore fishing activities have been noted for the subantarctic islands and mainland New Zealand shores (Cawthorn 1985).

SOURCES AND DISTRIBUTION

From the approach of Ryan (1987b), it is appropriate to identify three categories of plastic debris on shores throughout the region.

1. Material having a local onshore source.

2. Material originating from nearby fishing and shipping activities.

3. Material that has drifted from afar and that can be considered oceanic.

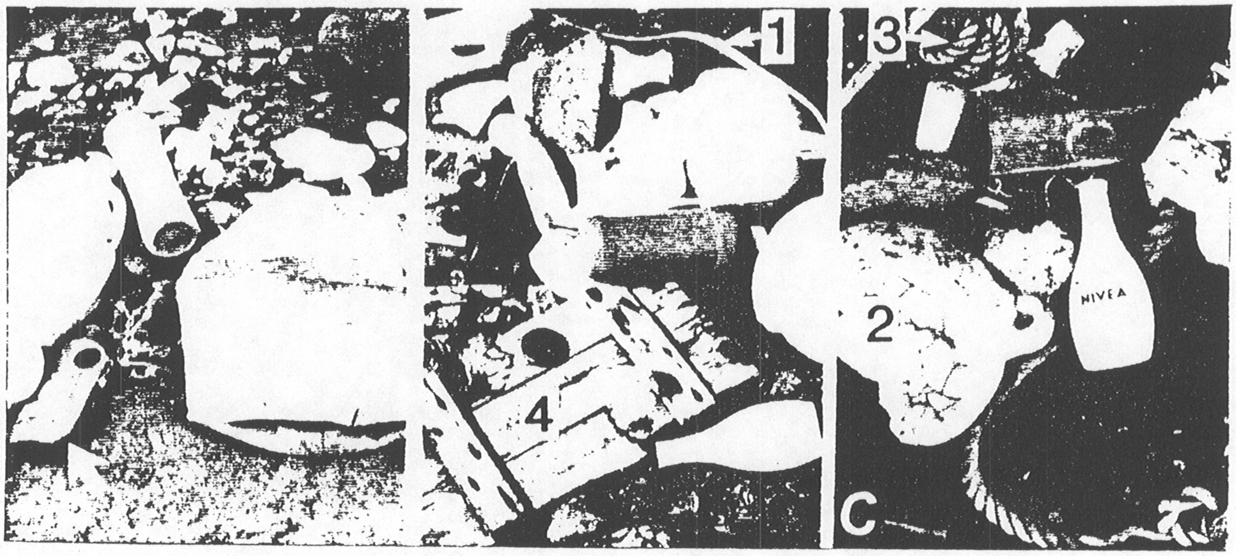


Figure 10.--Representative plastic items washed up on New Zealand's subantarctic islands: North West Bay, Campbell Island (A) and Derry Castle Reef, Auckland Islands (B and C). The large crushed container in (A) is of French origin and the two smaller items (arrow) are of United Kingdom manufacture. Note the polypropylene strapping (1), incipient crazing on the inside of broken high-density plastic fishing floats (2), cordage (3), and parts of wooden packing crates (4) in B and C.

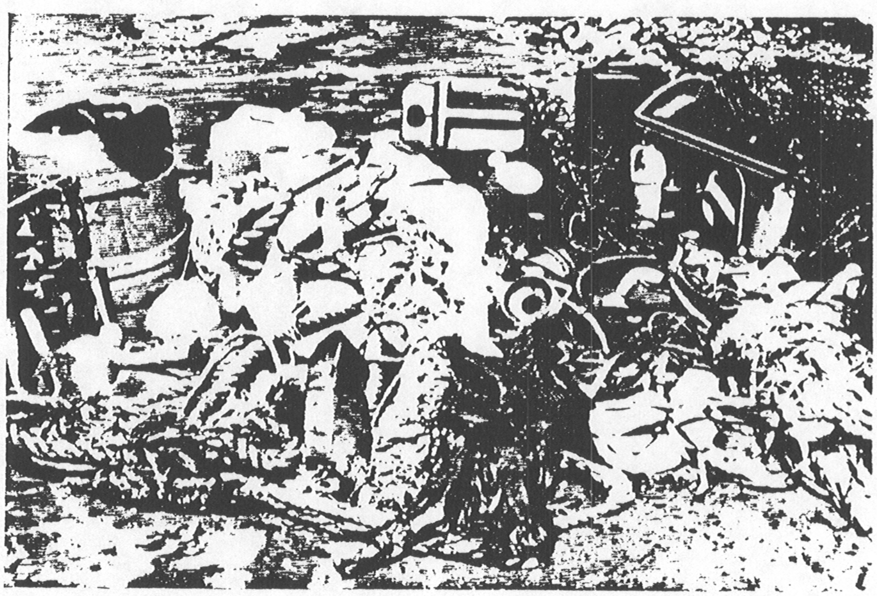


Figure 11.--Representative locally generated and oceanic plastic litter assembled from combing 100 m of beach at Makara, west coast near Wellington, New Zealand. Some of this collection has clearly come from fishing activities. (Photograph taken by M. Cochrane.)

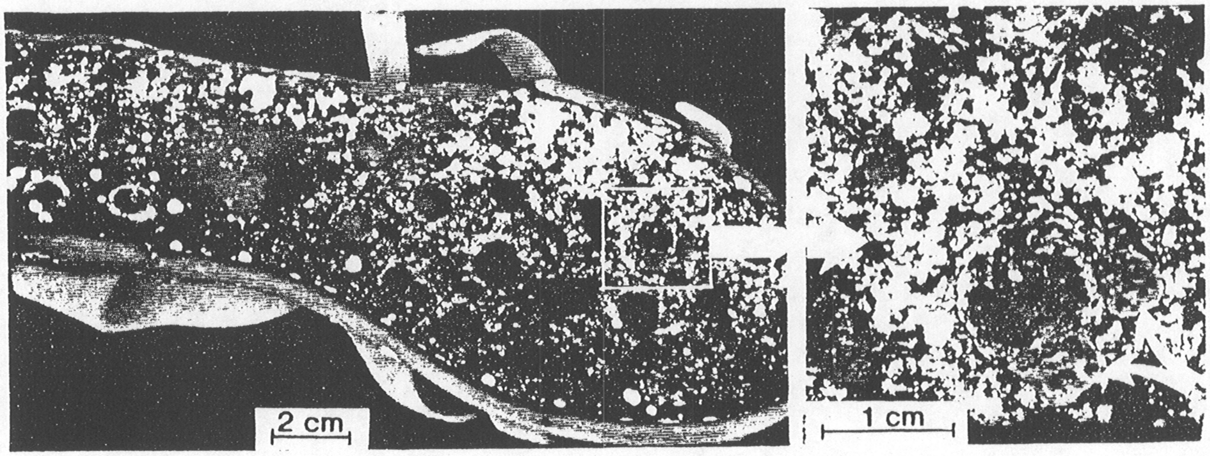


Figure 12.--Plastic sandal heavily encrusted with bryozoans, coralline algae, and clumps of the pink foraminiferan, *Homotrema rubra* (arrow). (Collected by K. A. Rodgers on Tuvalu.)

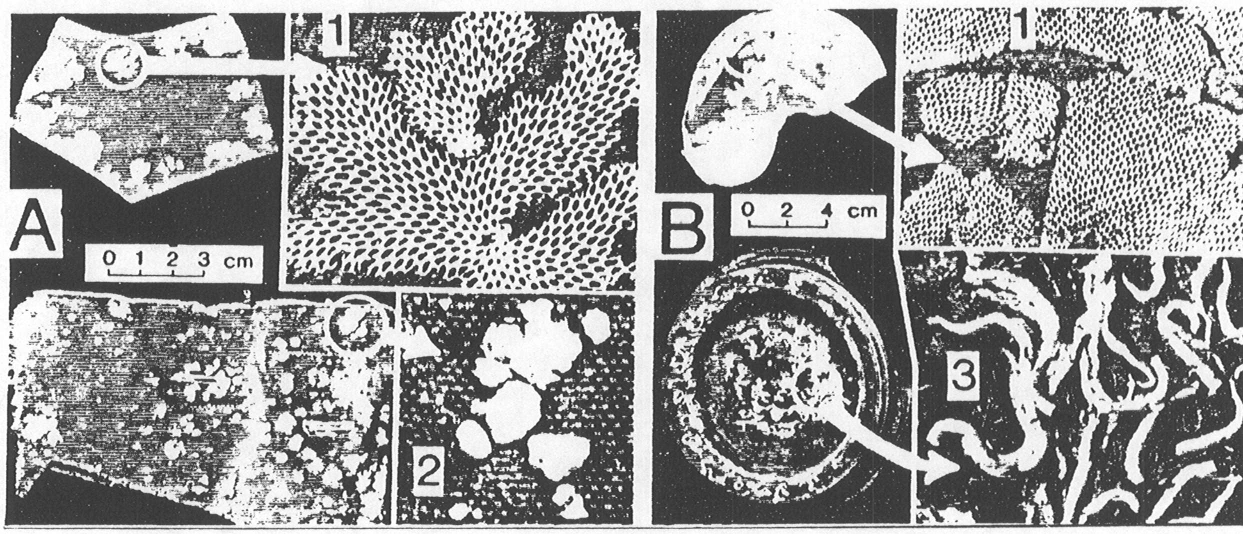


Figure 13.--Encrusted oceanic plastic items from Rarotonga (A) and Raoul Island (B). Note the bryozoans (1), coralline algae (2), and calcareous annelid tubes (3).

For the New Zealand coast and inshore waters, Gregory (1978) identified industrial centers as the principal sources (Fig. 2) of plastic mesolitter (mostly granules). This litter was material that was accidentally spilled in wharf and other cargo handling areas and at processing plants, and reached the sea through sewage and storm drainage systems as well as natural waterways. Subsequent dispersal was effected by coastal currents (Fig. 2). On populated islands (e.g., Tonga, Rarotonga), as on New Zealand shores, it is possible to separate plastic megalitter into two populations. One is probably of local (or domestic) origin, and the other comes from offshore sources and may have been adrift for some time. Casual visitors as well as indiscriminate and uncontrolled garbage dumping are responsible

BEACH CLEAN UP & SURVEY RECORD CARD

Date:____ General Location: ______________________

Exact Site on beach ______________________

Approx. size of area:___metres long by ___metres wide

Character of survey area rock, sand, mud, gravel, other ______________

Name of surveyor or organisation: ______________________

Contact address and tel. no: ______________________

An easy way to record the material you pick up is by counting in groups of five like this:
Bottles 𝍸 II Total [7]

HARD PLASTICS	Total	GLASS	Total
Bottles, containers		Bottles	
Tops		Light bulbs and tubes	
6-pack yokes		Broken fragments	
Buckets		ALUMINIUM	
Toys/combs		Cans, cartons	
Fragments		Foil/trays/wrapping	
Other		Other	
FOAM PLASTICS		TIN/STEEL	
Trays/cups/packaging		Tins/cans	
Fishing floats		Drums	
Foam fragments		Wire	
Other		Bottle tops	
PLASTIC SHEET AND FIBRES		Other	
Plastic sheets		PAPER	
Plastic & cellophane bags		CARDBOARD	
Fishing nets		TIMBER (leave driftwood on beach)	
Fishing lines (approx. length in metres)		CLOTH ITEMS	
Other rope/cord (approx length in metres))		RUBBER ITEMS	
Packing tape/strapping - cut		FOREIGN DEBRIS (describe overleaf)	
Packing tape/strapping - uncut		ENTANGLED/STRANDED ANIMALS (describe overleaf)	

ESTIMATE OF TOTAL VOLUME OF RUBBISH COLLECTED FROM YOUR AREA ______________

THANK YOU FOR COMPLETING THIS SURVEY CARD. PLEASE RETURN IT TO YOUR BEACH CO-ORDINATOR, OR YOUR LOCAL DEPARTMENT OF CONSERVATION OFFICE, OR POST TO ANNIE WHEELER, MARINE DEBRIS NETWORK, C/O DEPARTMENT OF CONSERVATION, P O BOX 8 NEWTON, AUCKLAND.

DETAILS OF ENTANGLED/STRANDED ANIMALS

Identify bird or animal ______________

Cause of injury or death ______________ If the creature is still alive, seek help from your beach co-ordinator, or local RSPCA, DOC office or Forest and Bird. Take photographs.

DETAILS OF FOREIGN DEBRIS

Describe item and the country you think it is from ______________

WHERE DO YOU THINK MOST OF THE RUBBISH YOU HAVE COLLECTED HAS COME FROM? (ie fishing boats, picnickers, household rubbish, foreign boats etc)

____

The NZ Marine Debris Network is a coalition of conservation groups who are concerned about the issue of marine debris and coastal pollution and its effect on wildlife. The Network includes representatives from the Department of Conservation, Greenpeace, Royal Forest and Bird Protection Society, University of Auckland, RSPCA, and the World Society for the Protection of Animals.

One of the aims of the Network is to co-ordinate the efforts of the many groups and individuals thoughout the country who are involved in beach clean ups and to carry out a survey of the debris collected off New Zealand beaches. This information can then be used to determine the main types and sources of the debris that litters our beaches. It will contribute to a national marine debris data base, and will help develop solutions to marine debris pollution.

Your participation in this beach clean up is an important contribution to an on-going nationwide effort.

GUIDELINES FOR COLLECTORS

1. Carry out your beach clean-up and survey at low tide.
2. Make sure you have warm clothing, and sun protection if necessary.
3. Wearing rubber or gardening gloves can be a good idea.
4. Before you start: make sure you've got your record card and board, pen and rubbish collection bags.
5. Take something to drink and perhaps a snack.
6. Work in small groups, so some of you can be picking up and sorting the rubbish into categories for recycling (see below) while one person is recording the details on the survey record card.
7. Know who your beach co-ordinator is and where to find them. Be clear about what area you are meant to be surveying.
8. Know where the rubbish collection point is.
9. Report any entangled animals to your co-ordinator and take photos if possible.
10. Give your record card back to your co-ordinator or post to the address on the other side of this form.
11. MAKE SURE YOU SEPARATE YOUR RUBBISH INTO DIFFERENT BAGS WITH 1. PLASTICS, 2. GLASS, 3. PAPER, 4. ALUMINIUM CANS, 5. TINS; AS ALL THIS MATERIAL IS GOING TO BE RECYCLED.

Figure 14.--Standard record card used in New Zealand coastal plastic pollution surveys.

for much of the former; some must also come from vessels operating in local waters. The most unsavory items found during the course of these surveys were soiled (disposable) baby diapers, syringes, and discarded pesticide or agricultural chemical containers. Litter coming from distant offshore sources is considered oceanic. It is characteristically embrittled and sports an encrusting biota (see below).

Around the subantarctic islands, plastic macro- and megalitter concentrate on west-facing (i.e., windward) shores, whereas little reaches their eastern (leeward) coasts (Gregory 1987). The dominating influence here is the strong West Wind Drift Current of the Southern Ocean (Lutjeharms et al. 1988). The same pattern is repeated on southwest Pacific island shores. Here, however, it is the eastern shores--those facing into the southeasterly trade winds--onto which plastic meso-, macro-, and megalitter are herded (Figs. 3-8). Further, in several instances, it is possible to identify crude decreases in quantities of plastics in the downdrift direction (e.g., Viti Levu, Tongatapu, and Rarotonga; Figs. 5, 6, and 8). The encrusting biota (see below) of many megalitter items suggest they have been afloat for some time. These are part of the global oceanic population of pelagic litter. Plastic granules on Australian, New Zealand, and Fiji shores can have their major origins in local suppliers and manufacturers.

Norfolk, Raoul, Vanua Mbalavu, Tongatapu, and Rarotonga have no local sources for virgin plastic granules, and lie upwind from regional ones. Nibs on these shores must have come from the same global oceanic population of pelagic plastics and are dispersed by the southeast trade winds. A possible source exists in French Polynesia, which lies upwind, but I have no data for this region.

Although plastic macro- and megalitter on eastern Australian shores have not been surveyed, quantities of this litter and the resin granules appear to be much lower than at equivalent sites in New Zealand. This difference probably reflects coastal current and broad oceanic circulation patterns as well as persistent winds that blow offshore or parallel to the coast over this region. On the other hand, drift pumice is quite common on these shores, as it is on the shores of many Pacific islands (Sachet 1955). Much of the plastic litter on popular recreational beaches of Australia, New Zealand, and larger southwest Pacific islands comes from casual visitors and day trippers; it is dominated by food and confectionery wrappings and drink bottles. This material is seldom conspicuous on isolated shores. From these remote places, there is evidence that much plastic debris comes from fishing-related or other shipping activities (Cawthorn 1985, 1987; Mattlin and Cawthorn 1986; Gregory 1987, 1990).

Attention has already been drawn to the accumulation of plastic debris on the windward shores of several southwest Pacific islands. The materials involved are mostly of oceanic origin and also from fisheries-related and shipping activities, and their quantities on west- and north-facing (leeward) shores are minimal. The principal urban population centers of Tongatapu, Rarotonga, and Upolu (Western Samoa) are all situated on north-facing coasts along which much locally generated plastic has spread.

Plastic items, categorized by country of origin (when possible), are summarized in Table 4 for New Zealand's subantarctic islands and for subtropical Raoul Island. Some items are truly oceanic (e.g., an Argentinian fishing float reaching the Snares), but most appear related to regional fishing activities. South Korean, Taiwanese, and Japanese vessels are common in these waters, so the dominance of Asian-sourced artifacts is not unexpected. The Russians also have a considerable presence, but one that is not reflected in the seaborne litter. Personal experience on a Russian research vessel reveals that they generate very little plastic, and discarded paper and cardboard packaging are incinerated.

The regional distribution of dispersed pelagic or oceanic plastics is schematically summarized in Figure 9. It has been inferred (Gregory et al. 1984; Gregory 1990) that major oceanic fronts such as the Polar, Subantarctic, Subtropical, and Tropical Fronts, and eddies from the East Australian Current have important influences on the distribution and abundance of litter. They act as barriers arresting the spread of material, and along these barriers the material is also concentrated and carried. For example, Bourne and Clarke (1984) noted an accumulation of garbage in the Humbolt Front off Valparaiso, Chile. Observations in the Hauraki Gulf, northern New Zealand, show that densities of plastic granules taken in tows made along windrows may exceed 10,000 km^{-2}, whereas densities in tows transverse to the windrows may be as few as 1,000 km^{-2} (Gregory, unpubl. data).

Table 4.--Summary of numbers of plastic items having identifiable countries of origin.

Country of origin	Subantarctic islands	Raoul Island
Asia	11	5
United Kingdom	5	1
New Zealand	4	6
Australia	3	2
Spain	2	--
Bulgaria	1	--
France	1	--
Norway	1	--
U.S.S.R.	1	1
Argentina	1	--

ENCRUSTING BIOTA

Plastics and other synthetic litter afloat on surface waters of the ocean are an important and expanding, although little studied, ecological niche for a pseudoplanktic biota of the kind commonly present on *Sargassum* (Winston 1982; Butler et al. 1983). Gregory (1978) noted that granules from beaches of northernmost New Zealand were sometimes encrusted by the bryozoan *Membranipora tuberculata*. This is a tropical species and has also been found on drift plastics from Australia, Norfolk and Raoul Islands, and Fiji, Rarotonga, and Tongatapu. It was inferred that there had been eastward dispersal across the north Tasman Sea by way of eddies in the East Australian Current (Gregory 1978). Other encrusting taxa identified during past and present studies include further bryozoan species awaiting identification, coralline algae, calcareous annelids, barnacles, a hermatypic coral, and the pink foraminiferan *Homotrema rubra* (Figs. 12, 13). Encrusters are less common on artifacts from the subantarctic, where only goose barnacles (*Lepas* spp.) and the annelid *Spirorbis* have been recognized.

It is evident that pelagic plastic litter may be an important vector in the transoceanic and regional dispersal of a varied biota and may increase the chances of migration to distant shores, including isolated islands, as contemplated by Ryan (1987b).

DISCUSSION

The general environmental problems of the southwest Pacific region, with its limited financial and natural resources, have received wide attention (e.g., Chan 1973; Salvat 1979; Izrael et al. 1981; Dahl and Carew-Reid 1985; Carew-Reid 1988). Plastics are an unnecessary additional contaminant to the region, and the environmental implications to be drawn are those that have been identified elsewhere (Laist 1987) and need no further elaboration. For animals these implications include death or debilitation through entanglement; blockage of the intestinal tract through ingestion, leading to starvation and death; ulceration of delicate tissues by jagged plastic fragments; and reduction in quality of life and reproductive performance. In addition, large items can be hazards to shipping. The aesthetic concerns expressed about plastic pollution also must be acknowledged. Unsightly accumulations of locally generated or oceanic plastics on beaches could be to the detriment of tourism (Prasad 1987). Soiled diapers, used syringes, and medicinal and pesticide containers stranded or abandoned on beaches will discourage even the most hardy of tourists.

The oceanic problem can be addressed through MARPOL and the London Dumping Convention. The local problem needs to be approached with cultural delicacy, for traditional practice and attitudes towards refuse disposal are in many ways rather casual (Anonymous 1976). Educational efforts, directed primarily at the young (Bryant 1988), will need to draw on and develop from traditional Pacific ways.

The very attributes that mankind finds desirable in plastics--lightness, strength, manufacturing adaptability, flexibility, inertness, resistance to degradational processes, transparency, and prolonged shelf life in packaging--are also the reasons they are today a globally important marine pollutant (Andrady 1988; Johnson 1988).

It is difficult to estimate the rate at which plastics disappear or are adsorbed into the environment (Gerrodette 1985). And while the breakdown of plastic compounds in itself may create few problems, the effects of released additives such as antioxidants, retardants, and biocides have never been assessed, only speculated about (Gregory 1978). Locally generated litter is likely to be fresh in appearance, while much of the oceanic and offshore-generated plastic litter stranding on these tropical and subtropical Pacific shores is chalky, crazed, and embrittled, all evidence of oxidative aging and photodegradation. Whether this occurs while it is afloat or after it is stranded on the shore has not been established. Circumstantial evidence suggests that aging is more rapid once artifacts are stranded high and dry on a beach (Gregory 1983). On the New Zealand coast, the extent of degradation apparently decreases southwards, although a detailed survey to confirm this claim has not been undertaken. Similarly, the proportion of degraded virgin granules is much greater on the tropical shores than it is on temperate ones (Table 5) (Gregory 1983, table 1). On high-latitude subantarctic shores, crazing is less evident and much breakdown occurs through mechanical abrasion and battering (Gregory 1987).

The extent of crazing and embrittlement of plastic granules (Table 5) and megalitter items observed on Raoul, Rarotonga, and Tonga suggest that a survival time of 5 years (Gregory 1983) may be overly generous. Evidence indicates that plastics degrade more rapidly in the Australian and New Zealand region than they do in equivalent Northern Hemisphere latitudes, although contrary to popular belief, the reason is not necessarily related to higher ultraviolet values (Sharman 1987). Controlled experiments and observations on rates of plastic degradation around the world are needed if we are to understand adequately the population dynamics of pelagic plastics

Table 5.--Relative numbers (in percentages) of fresh, slightly degraded, and highly degraded plastic granules from selected localities.

		Increasing degradation ———>		
Locality	Number	Fresh	Slightly degraded	Highly degraded
Fiji	163	18	45	37
Raoul	25	24	52	24
Rarotonga	70	19	41	40
Tonga	60	20	30	50
Auckland, New Zealand	216	79	13	8
Botany Bay, Australia	73	53	40	7

and to establish whether an equilibrium state between accumulation (strandings) and losses in environmental sinks (disappearance from view) has been already reached.

CONCLUSIONS

Although pollution by plastics of the southwest Pacific marine environment has not yet reached the magnitude evident in waters adjacent to more heavily populated, industrialized, and fished regions of the Northern Hemisphere, it is a developing problem and cause for concern.

Increased fishing activities across the region, and in particular drift gillnetting, are likely to escalate presently identified problems.

Regional distribution and dispersal are influenced by proximity to sources, oceanic current and circulation patterns, and prevailing winds. Oceanic fronts may have a key role in defining boundaries to zones with broadly similar areal densities of pelagic plastics.

Population dynamics of pelagic plastics across the southwest Pacific as well as globally are not well understood, and more information is needed on the "sinks" of this material.

There is need to educate the public about the environmental problems arising from the indiscriminate disposal of plastics and other persistent synthetic compounds.

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THE MARINE PLASTIC DEBRIS PROBLEM OFF SOUTHERN AFRICA: TYPES OF DEBRIS, THEIR ENVIRONMENTAL EFFECTS, AND CONTROL MEASURES

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ABSTRACT

Plastic debris is a global marine pollutant which is inflicting ever-increasing environmental and financial costs. In the seas off southern Africa and the adjacent Southern Ocean, entanglement has been recorded for at least 5 species of marine mammals, 13 seabird species, 2 turtles, and 6 shark species. Plastic ingestion has been recorded from 7 marine mammal species, 36 seabird species, 2 marine turtle species, and 7 shark species. The incidence in invertebrate taxa is not known. At present, entanglement does not pose a threat to the survival of any populations off southern Africa, but the recent introduction of a driftnet fishery to the South Atlantic and Indian Oceans and the suffering frequently associated with entanglement are causes for concern. By contrast, ingestion of plastic particles may adversely affect almost the entire population of species that do not regurgitate indigestible objects, with large, accumulated plastic loads reducing feeding efficiency or obstructing the digestive tract. Off southern Africa, generalist, surface-feeding, pelagic taxa such as certain procellariiform seabirds (petrels and albatrosses) and juvenile marine turtles are at risk from plastic ingestion. The incidence of ingested plastic in some species exceeds 90% of the population. The major financial cost of marine plastic debris is the reduced aesthetic appeal of coastal areas, which adversely affects the tourist industry. In South Africa alone, approximately R10 million is spent annually on cleaning beaches, where plastic makes up more than 90% of all stranded debris.

To address the problem of marine debris requires knowledge of the sources of various pollutants. Beach surveys readily assess the most abundant types of plastic debris, and from these data their sources can be inferred. Disposable packaging accounts for more than half the large plastic objects on southern African beaches, with most of the remainder composed of fishing gear. Sheet plastic (bags and wrappings) is the most abundant single type of plastic. Among small particles, virgin industrial pellets and fragments of other products predominate.

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Using these findings to assign culpability and to elicit assistance, four approaches are being used to tackle the problem of marine plastic debris off southern Africa: education, product substitution, recycling, and legislation. As a short-term measure, specific types of artifacts responsible for most entanglements (e.g., hi-cone six-pack yokes, packing straps) and ingestion (e.g., virgin pellets, plastic bags) have been targeted for action. These approaches to control marine plastic pollution are discussed in relation to the highly diverse socioeconomic conditions prevailing in southern Africa.

INTRODUCTION

Much concern recently has been focused on the problems associated with anthropogenic marine debris, particularly as regards plastic (Shomura and Yoshida 1985; Laist 1987; Wolfe 1987). A variety of approaches has been adopted to tackle these problems, but have concentrated on maritime legislation (e.g., Bean 1987; Lentz 1987) and on awareness campaigns in developed, first world communities (e.g., Neilson 1985). Other than international maritime legislation, there have been few attempts to tackle the growth of marine debris arising from third-world communities. The southern African region comprises virtually the entire socioeconomic spectrum, and is to a large extent isolated from the world's major manufacturing centers. It is thus a useful area for examining the efficacy of various measures taken to limit persistent debris production. This paper reviews the occurrence of anthropogenic marine debris off southern Africa and in adjacent oceanic areas, and summarizes the known environmental effects of debris. The approaches used to identify the sources of marine debris and to control the amount of litter entering the sea are discussed.

THE SEAS OFF SOUTHERN AFRICA

Southern Africa has an unindented coastline, with few large bays or inlets (Fig. 1). Strong wave action is characteristic of much of the coast, with sandy beaches comprising almost 70% of the coastline. The continental shelf is narrow (<50 km wide) off the east coast, moderately broad (up to 150 km wide) off the west coast, and is most extensive off the south coast, where the Agulhas Bank extends more than 200 km offshore.

There are two main current systems. The cool (10°-16°C) Benguela Current flows north along the west coast, and is characterized by localized upwelling of cold, nutrient-rich bottom water when surface waters are advected offshore (Shannon 1985). The warm (22°-28°C) Agulhas Current flows south, close inshore along the east coast until it reaches the Agulhas Bank, where it moves offshore. South of the subcontinent, the Agulhas Current retroflects to flow eastward in oceanic waters to the north of the Subtropical Convergence (Lutjeharms 1981). However, large (500-km diameter) eddies formed at the retroflection zone frequently transport Agulhas Current water into the South Atlantic (Lutjeharms 1988; Lutjeharms and Valentine 1988). Elsewhere to the south of the subcontinent, the predominant surface flows are eastward, associated with the West Wind Drift (Lutjeharms et al. 1988).

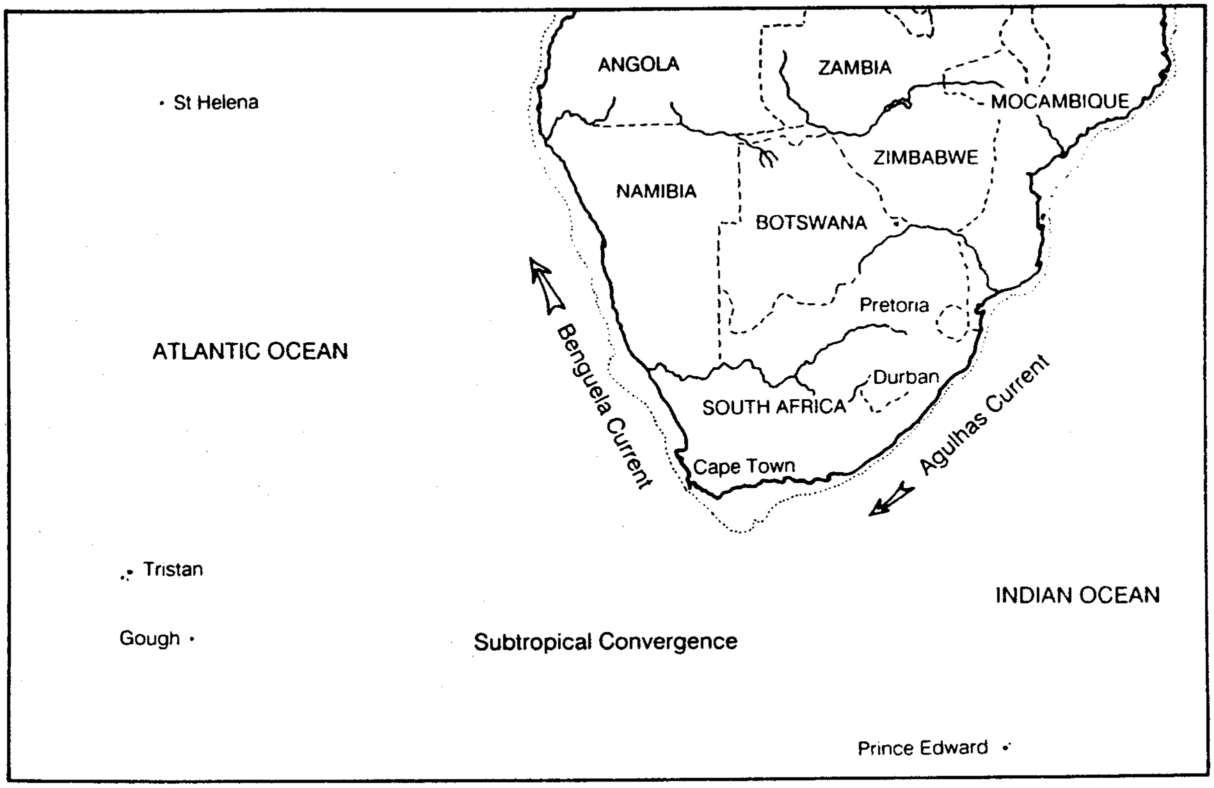

Figure 1.--The southern African region and adjacent oceans. The stippled line indicates the approximate edge of the continental shelf.

Most merchant ships in the area travel around southern Africa following the Cape sea route between Europe-North America and the Persian Gulf-Southeast Asia. This route runs close inshore along the south and east coasts of southern Africa, only moving offshore off the west coast. There is relatively little transoceanic merchant trade to either South America or Australia.

Commercial fisheries off southern Africa are concentrated on the broad continental shelves off the south and west coasts, where there are extensive demersal (bottom trawl) and pelagic (purse seine) fisheries (Crawford et al. 1987). There is a limited prawn fishery off the east coast, and a longline tuna fishery in oceanic waters. Gillnets were little used in the region until 1989, when oriental vessels started using driftnets more extensively in both the South Atlantic and South Indian Oceans (Ryan and Cooper in press).

THE DISTRIBUTION OF PLASTICS AND OTHER DEBRIS AT SEA

Little has been recorded of the distribution and abundance of plastic and other debris at sea off southern Africa. The abundance, distribution, and movements of tar balls at sea have been documented for two regions off the southern African coast, with a view towards identifying coastal areas vulnerable to oil pollution (Shannon et al. 1983). The abundance of small plastic particles (<10 mm diameter) also has been estimated from surface neuston trawls. Morris (1980) reported densities ranging between 1,300 and 3,600 virgin industrial pellets km^{-2} in oceanic waters of the Cape Basin west of Cape Town.

The density of plastic debris in coastal waters off the southwestern Cape averaged 3,640 particles km^{-2}, derived from over 1,200 neuston trawls conducted at monthly intervals during 1977-78 (Ryan 1988a). Seasonal patterns of distribution and abundance were related to probable source areas and transport at sea. However, the highly clustered dispersion of particles, presumably due to fine-scale convergence zones, resulted in great variances in debris abundance estimates (range 0-445,000 particles km^{-2}), largely as a consequence of the relatively small sampling area (190 m^2 per trawl). Foamed plastics and fragments of manufactured articles were the most abundant types of particles, but virgin industrial pellets accounted for most of the mass (mean 42.4 g km^{-2}; Ryan 1988a). It appears that at least a significant proportion of the debris arises from local sources, with concentrations inshore and close to harbors (Ryan 1988a, cf. Morris 1980). However, there is also evidence that the Agulhas Current is an important debris vector (Ryan 1988a).

A small number of neuston trawls (39) in oceanic waters south of southern Africa in the Agulhas retroflection area collected only two plastic particles, both fragments of manufactured articles (P. G. Ryan unpubl. data). This gives a density estimate for the area of only 50 particles km^{-2}, similar to the density in the Southern Ocean south of New Zealand (Gregory et al. 1984).

Ryan (1988a) found that the density of large (>100 mm diameter) objects counted from a low-flying plane was an order of magnitude greater 10 km from the shore (19.6 objects km^{-2}) than 50 km offshore (1.6 km^{-2}) in the area between Cape Town and Saldanha Bay, where the merchant shipping lane runs close inshore. This offshore gradient is likely to be less marked farther north off the west coast where the continental shelf is broader (hence fishing grounds more extensive) and the shipping lane runs farther offshore. In oceanic waters south of the subcontinent, in the region of the Agulhas retroflection, ship-based counts provided density estimates of between 0.04 and 0.09 large objects km^{-2} (P. G. Ryan unpubl. data).

These data refer only to floating debris. Virtually nothing is known about debris on the seabed off southern Africa. Debris comprised of materials denser than seawater presumably does not disperse far from source areas. Such items occasionally are caught in bottom trawls off the west coast (B. Rose pers. commun.; pers. observ.). Floating debris can also sink if it supports sufficient sessile organisms or entangles enough animals to increase the density above that of seawater. Such objects have a much greater dispersal capability than do plastics that are denser than seawater.

IMPACTS OF MARINE DEBRIS

Marine debris has both environmental impacts and financial costs. The major financial burden results from the reduced aesthetic appeal of polluted marine systems. Beaches are important for the >R2,000 million per annum tourist industry in southern Africa, and their appeal is reduced when they are littered with stranded debris. In South Africa alone some R10 million is spent annually on cleaning litter off beaches.

Apart from the accumulation of unsightly debris, the main environmental impact associated with marine debris is animal mortality through entanglement in and ingestion of debris. In addition, it has been suggested that anthropogenic debris is having some ecological effect by increasing the amount of available substratum onto which sessile organisms can settle (Carpenter and Smith 1972; Winston 1982), and it is possible that debris has increased the rate of propagule dispersal to islands (Ryan 1987b). However, the significance of the latter two impacts has not been determined.

Entanglement off Southern Africa

Entanglement involves animals becoming enmeshed in objects that impede movement, causing drowning, starvation, or reduced fitness, or restrict growth, cutting deep wounds into growing animals. This typically involves fairly large pieces of debris, and the apparent suffering associated with entanglement engenders considerable public concern.

Representatives of five marine vertebrate classes are known to have become entangled in debris off southern Africa (Table 1); there are no data for invertebrate groups. Most records are from coastal waters (where there are most observers), but a few entangled seals and birds have been found at subantarctic islands. Overall, the incidence of entanglement is fairly low, with only one species, the great white shark, *Carcharodon carcharias*, having more than 1% of individuals examined entangled in debris. There may be some cause for concern along the south coast, where 14% of stranded birds are entangled in debris (n = 97), with 28% of the vulnerable jackass penguin, *Spheniscus demersus*, entangled (n = 32, P. G. Ryan unpubl. data).

However, interpretation of the incidence of entanglement is complicated by different sampling techniques. For example, recoveries of banded crested terns, *Sterna bergii*, in southern Africa indicate that 14.2% (n = 267) of birds are captured after being entangled in debris, whereas only 2.2% (n = 46) of stranded birds were found entangled ($\chi^2 = 5.23$, $P < 0.05$; FitzPatrick Institute unpubl. data). And yet it is to be expected that the proportion of entanglement among stranded animals is higher than that among the general population, although the exact relationship is unclear. Also, it is not possible to infer the consequences of a given level of entanglement on population trends. Northern fur seal, *Callorhinus ursinus*, numbers have been decreasing apparently at least partly as a result of a 0.4% frequency of entanglement (Fowler 1987). A similar entanglement frequency has been recorded at some Cape fur seal,

Table 1.--A summary of the known incidence of entanglement of marine animals in plastic objects and other debris off southern Africa, excluding the by-catch of nontarget species during fishing operations (including shark exclusion nets). Based on Shaughnessy (1980), Balazs (1985), and (unpubl. data) from G. Avery, P. B. Best, N. Rice, G. J. B. Ross, and the Natal Sharks Board.

Taxon	Type of debris	Frequency of occurrence
Cetaceans	Ropes, nets	Three plus species, apparently infrequent.
Seals	Ropes, nets, line 92% Packing straps 6% O-rings 2% Wire <1%	Cape fur seals 0.12%, but 0.6% in one colony. Two records at subantarctic islands.
Birds	Nets, rope, line 89% Plastic bags 11%, Six-pack yokes	Thirteen species, 0.6% of stranded animals but up to 14% locally.
Turtles	Rope	Two species.
Fish	All packing straps	Six species of sharks, 0.2% of shark-net catch, incidence ranges 0-1.4%.

Arctocephalus pusillus, colonies (Shaughnessy 1980), and yet this species' population is increasing by 3.7% per year (David 1987).

The types of objects causing entanglement off southern Africa vary among taxa (Table 1). However, most items are either fishing gear (rope, netting, and fishing line) or disposable packaging (primarily plastic packing straps and plastic bags). Only one item was not made of plastic; a single seal was found with a piece of wire caught around its neck (Shaughnessy 1980).

These data on entanglement ignore the incidental catch of animals during commercial fishing operations. Some birds and mammals are caught in demersal trawls (e.g., Ryan and Moloney 1987) and by the longline fishery (e.g., Ryan and Rose 1988), but for at least these taxa the fishery by-catch is relatively small (cf. Tull et al. 1972; Piatt and Nettleship 1987), due largely to the limited use of gillnets. The impact of the recent expansion of oriental driftnet fisheries in oceanic waters of the South Atlantic and South Indian Oceans needs urgent investigation. The killing of seabirds for food by fishermen is an ongoing problem (Cooper 1977; Ryan and Rose 1988).

Table 2.--A summary of the known incidence of marine animals ingesting plastic objects and other debris off southern Africa. Based on Hughes (1973), Ryan (1987a), and unpubl. data from P. B. Best, J. H. M. David, G. J. B. Ross, and the Natal Sharks Board.

Taxon	Type of debris	Frequency of occurrence
Cetaceans	Plastic bags 8 Plastic bottles 1 Packing strap 1	Seven species, 3.0% of stranded animals.
Seals	--	No records.
Birds	Virgin plastic pellets 56% Plastic user fragments 43% Wood, tar balls, paint, glass, and aluminium foil 1%	Thirty-six species, incidence ranges 0-92% with 10 species >50% and 4 species >80%.
Turtles	Plastic bags 75% Virgin plastic pellets 25% Glass 1 piece	Two species, 11.1% of stranded animals.
Fish	Plastic bags 82% Plastic bottles 12% Nets and line 6%	Seven species of shark, 0.3% of shark-net catch, incidence ranges 0-6%.

Debris Ingestion off Southern Africa

The effects of debris ingestion are seldom as dramatic as those of entanglement, but ingested debris can cause death or debilitation by obstructing the digestive tract (e.g., Balazs 1985; Fry et al. 1987) or reducing meal size and the urge to eat (e.g., Ryan 1988b). Ingested plastic may also be a source of toxic chemicals (e.g., Ryan et al. 1988).

Ingestion of marine debris has been recorded for four vertebrate classes off southern Africa (Table 2); there are no data for invertebrate groups. Debris ingestion is much more prevalent than is entanglement, affecting over 90% of individuals of blue petrels, *Halobaena caerulea*, and great shearwaters, *Puffinus gravis*, breeding at oceanic islands (Ryan 1987a). The incidence of debris ingestion among southern African seabirds is among the highest in the world, largely due to the predominance of generalist, surface-feeding procellariiform seabirds (petrels, storm-petrels, shearwaters, and albatrosses) that do not frequently regurgitate indigestible objects and thus accumulate ingested plastic (Ryan 1987a, 1988c). The present incidence of debris ingestion by turtles may be greater than the 11% indicated in Table 2, because there are no observations subsequent to 1973. Debris ingestion by birds has increased since the late 1970's off southern Africa (Ryan 1988c).

Ingestion of debris off southern Africa by large proportions of populations of birds and turtles in particular is cause for concern. Almost all debris ingested is plastic that floats in seawater (Table 2). The few nonfloating debris items found in animals apparently are eaten ashore (e.g., gulls at refuse dumps, giant petrels at their breeding islands). Although the types of objects ingested are influenced by an animal's size (e.g., Ryan 1987a), two types of plastic objects make up the majority of ingested debris: virgin industrial pellets and plastic bags (Table 2). Reducing the abundance of these items at sea is the only long-term solution to the problem of debris ingestion.

TACKLING THE MARINE DEBRIS PROBLEM

Marine debris is extremely heterogeneous in terms of both the size and composition of artifacts and the wide range of their sources. This diversity makes the control of marine debris problematic. Examining the various impacts of marine debris highlights the types of debris responsible for most environmental problems. Off southern Africa these are discarded fishing gear, various types of plastic packaging (notably bags and packing straps), and small plastic particles (chiefly virgin industrial pellets). These types of debris warrant most attention, but the implementation of effective measures to reduce the amount of debris entering the sea requires knowledge of the sources of marine debris. It is evident that the general source of discarded fishing gear is the various fishing industries, providing a ready target for action. However, the sources of packaging and, to a lesser extent, industrial pellets are highly diffuse, complicating the assessment of culpability.

Using Beach Surveys to Identify Debris Sources

Beach surveys offer the simplest and most practical way to assess the relative abundance of various types of marine debris and to identify their probable sources (e.g., Merrell 1980; Vauk and Schrey 1987). However, one problem with stranded debris surveys is controlling for the selective removal of debris by beachcombers (see Ryan 1987b). Surveys at uninhabited islands avoid this problem. Figure 2 shows the numerical dominance of plastic articles and the much faster growth in amount of plastic debris compared with other debris types at Inaccessible Island in the Tristan group, central South Atlantic Ocean. Most of the debris identifiable as to country of origin derives from South America, and the proportion has been increasing: 32% in 1984, 36% in 1987, and 48% in 1988. Given the limited merchant trade across the South Atlantic, it is likely that much of the plastic debris reaching Inaccessible Island has drifted more than 3,000 km from South America (Ryan and Watkins 1988).

This contrasts with the situation on southern African beaches, where most identifiable debris derives from local sources. A survey of stranded debris at 50 sandy beaches between Cape Town and the Transkei was undertaken during June 1984. All large (>20 mm) articles within representative 50-m stretches of beach were collected (P. G. Ryan unpubl. data). Plastic made up more than 90% of stranded debris, and was recorded at all beaches sampled. Disposable packaging (e.g., bags, bottles; Fig. 3) comprised more

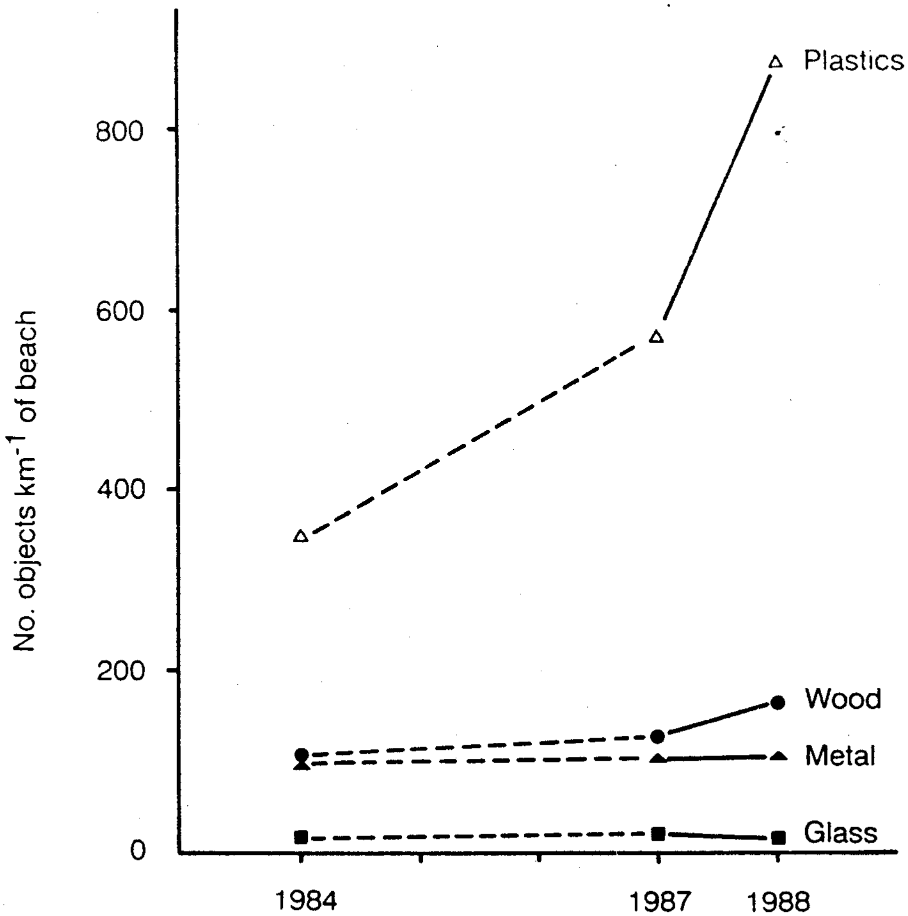

Figure 2.--The densities of various types of stranded debris at uninhabited Inaccessible Island during 1984 (Ryan 1987a), 1987 (Ryan and Watkins 1988), and 1988 (P. G. Ryan unpubl. data). Dashed lines between 1984 and 1987 indicate the lack of samples during this period.

than half of all plastic articles (57%), with fishing gear (netting, ropes, monofilament line, floats, traps, and fish boxes) making up most of the remainder (31%; Fig. 3). Almost half of the packaging was sheet plastic (bags and wrappings constituting 47% of packaging; Fig. 3), whereas polypropylene rope made up most of the fishing gear (85%).

The relative proportions of packaging and fishing gear among stranded plastic debris varied with distance from human settlements. Beaches in urban areas had a much greater proportion of packaging than either rural or island beaches (Fig. 4). This indicates that dumping of garbage from ships is not the only source of debris; urban areas in coastal South Africa also contribute significantly to marine debris loads (although selective removal of fishery-related products by beachcombers may contribute to the

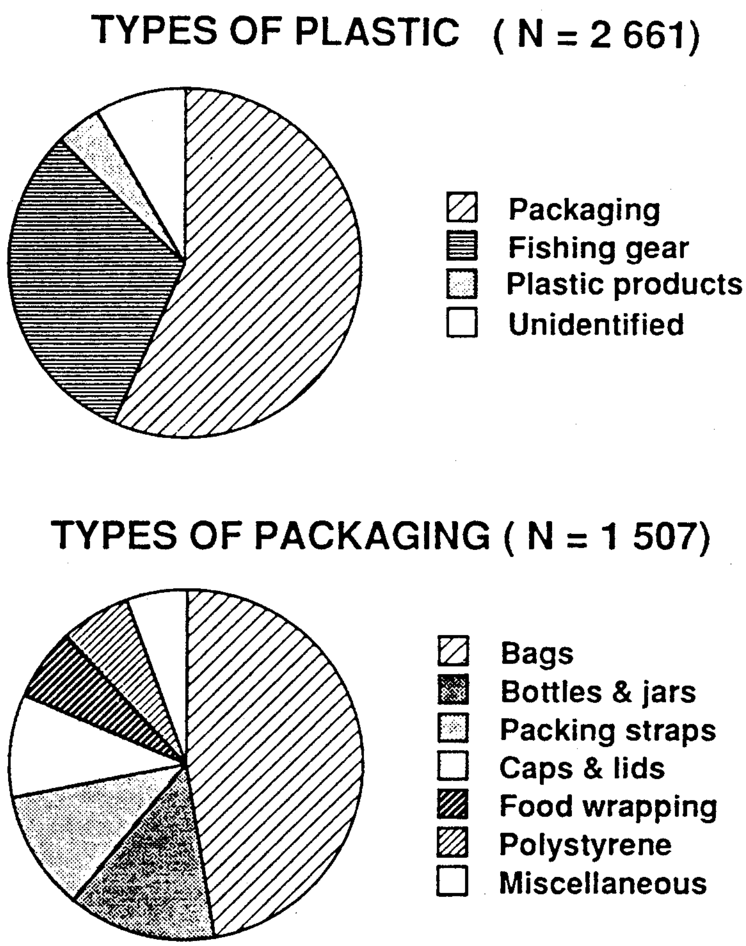

Figure 3.--The proportions (by number) of various functional groups of plastic articles found stranded on 50 South African beaches during June 1984.

differences). This is evident to anyone examining storm-water outlets draining urban areas, and concurs with current thinking that land-based sources may be more important contributors of debris to the marine environment than are vessels (Bean 1987, but see Pruter 1987; Wirka 1988). The mean density of packaging at urban beaches in South Africa (0.66 articles m^{-1} of beach) was greater than that at rural beaches (0.53 m^{-1}), although variances were great.

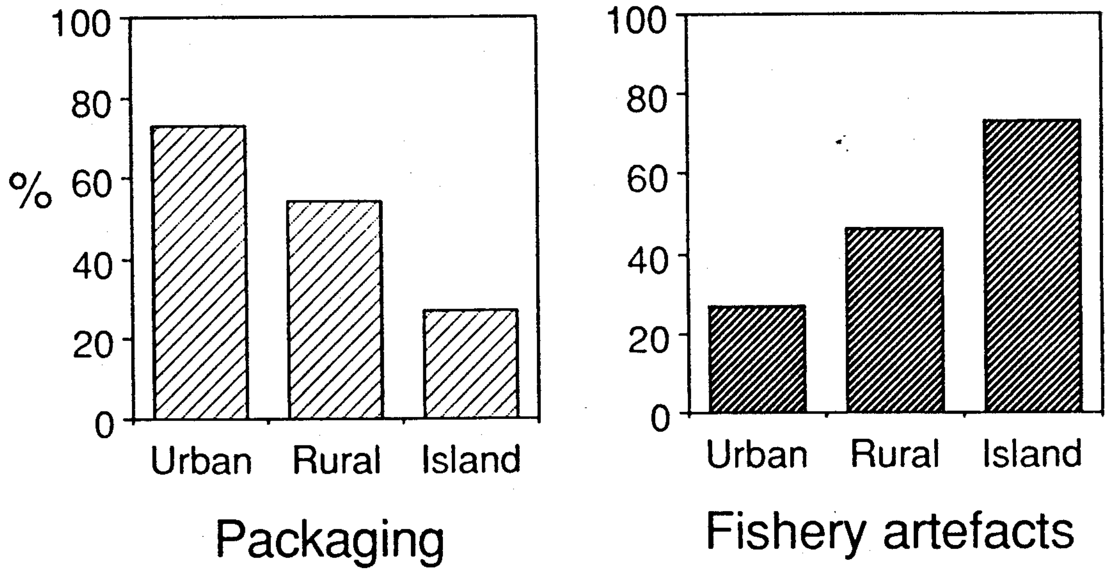

Figure 4.--The relative proportions (by number) of packaging and fishing gear stranded at urban (n = 26) and rural (n = 24) beaches in South Africa, compared with the situation at oceanic islands.

Virgin industrial pellets and fragments of plastic articles also are widespread and abundant on southern African beaches, with exceptional densities of up to 43,350 particles per meter of beach (88% industrial pellets, P. G. Ryan unpubl. data). Determining the origin of these items is more difficult than determining the origin of larger articles. However, at least some industrial pellets derive from local sources, where poor handling practices result in spillages, with transport to the sea in wastewater (pers. observ.).

Measures to Control Marine Debris in Southern Africa

The diverse nature of marine debris requires a multilevel approach to mitigating the problem. Four basic control tools are available: education, product substitution, recycling, and legislation. However, not all of these approaches are appropriate to tackle the different facets of the marine debris problem.

Ship-Based Sources

Ships are responsible for fishing gear (with the exception of monofilament line and other wastes from shore-based anglers) and a proportion of general refuse (packaging and other operational wastes). This source of debris has received more attention than have land-based sources (e.g., Dixon and Dixon 1981; Horsman 1982; Low et al. 1985; Pruter 1987), and is the subject of several international conventions (e.g., Lentz 1987). South Africa has agreed in principal to sign Annex V of the International

Convention for the Prevention of Pollution from Ships (MARPOL), which came into force at the end of 1988 and prohibits the dumping of all plastic products at sea. This will be a major advance, and South Africa's ratification of Annex V warrants expediting. Priority should also be given to Namibia, which became independent in 1989, acceding to MARPOL.

However, there are problems associated with enforcing Annex V of MARPOL (e.g., Bean 1987) which necessitate that its implementation in South Africa be coupled with an intensive education campaign aimed at all mariners. A representation to this effect has been made to the South African committee working on incorporating Annex V into national legislation (Dolphin Action and Protection Group 1989). In the interim, favorable responses have been received from several merchant lines and the South African Navy in response to requests to reduce the amount of debris dumped at sea (Dolphin Action and Protection Group 1988a, 1988b, 1989).

One problem area not covered by Annex V of MARPOL is the accidental loss of fishing gear at sea. There is no simple solution to this problem. The dumping at sea of damaged nets and other persistent debris by fishing vessels has officially been outlawed in South Africa since 1986 (Dolphin Action and Protection Group 1988a). However, captains of commercial fishing vessels currently are paid bonuses based on the cleanliness of vessels returning to port. This is perceived by the industry as being responsible for considerable dumping at sea, an action that could be avoided by linking bonuses to the amount of persistent debris returned to shore.

Land-Based Sources

There are two main types of marine debris derived from land-based sources: virgin industrial pellets and the diverse array of manufactured articles, principally disposable objects such as packaging and convenience items (Bean 1987). The loss of industrial pellets into the environment is limited to the plastics industry, which in southern Africa is a fairly small target for control measures. There is only one polymer producer in southern Africa (linked to the oil-from-coal plant at Secunda in the Transvaal), and almost all converters (manufacturers that convert industrial plastics into user products) are based in South Africa (Fig. 5). The industry has been apprised of the problem and is sympathetic. The recent large increases in the price of virgin pellets apparently have resulted in improved handling practices leading to reduced losses, but this needs verifying, and, if necessary, supporting with punitive legislation against accidental spillages.

A more intractable problem is that of general refuse being washed or blown into the sea. This type of debris derives from such a variety of sources that there is no simple target for control measures (Pruter 1987). Ultimately, the only solution is to educate the public to dispose of refuse correctly. There are ongoing antilittering campaigns in most southern African states, but these are proving insufficient to the task. The problem is complicated by the difficulty of communicating to a broad cultural and economic spectrum simultaneously. South Africa has the potentially disastrous combination of a burgeoning third-world population shopping in first-world supermarkets for products wrapped in first-world packaging,

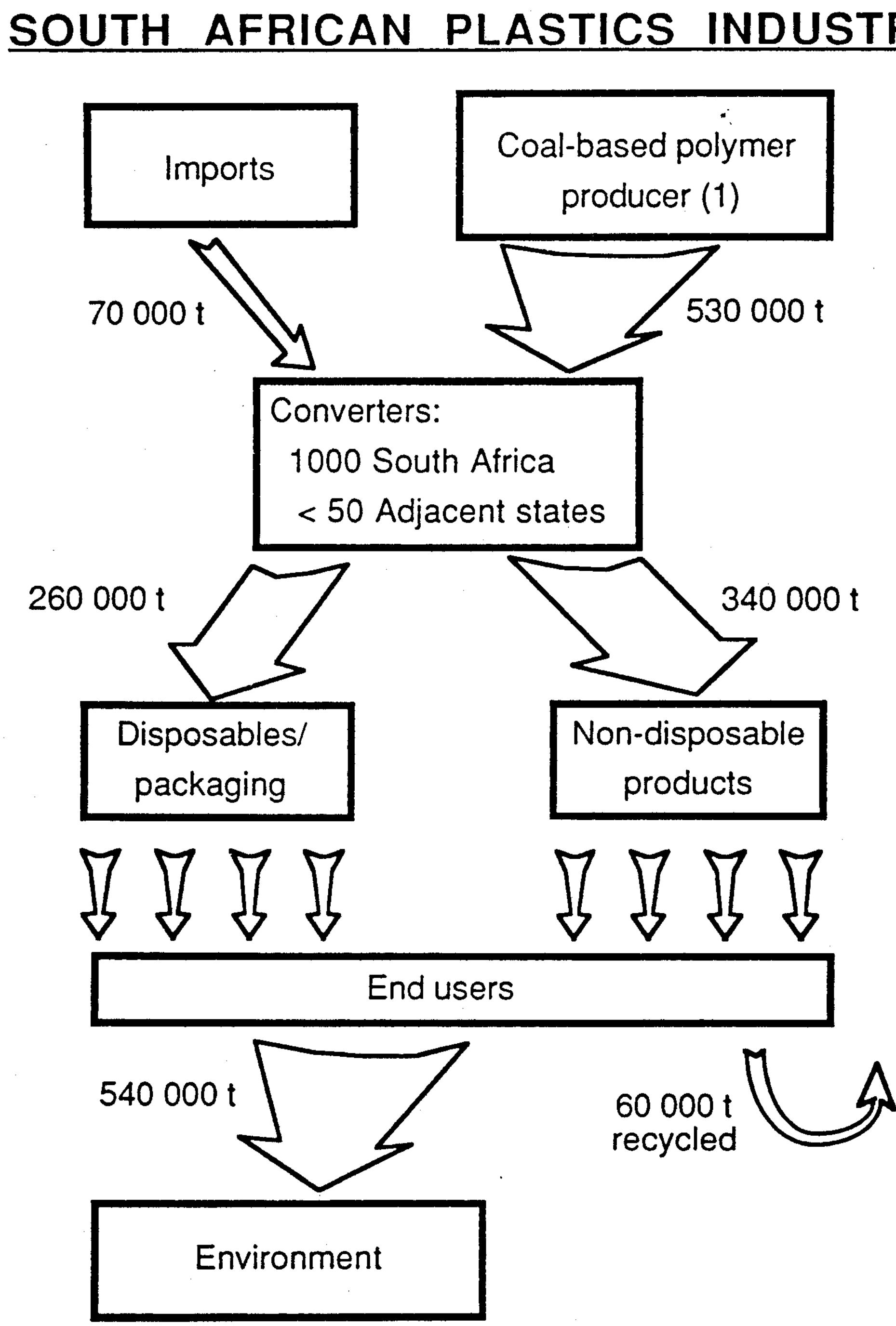

Figure 5.--The status of the South African plastics industry during 1988, showing the magnitude (metric tons) of flows between producers, users, and the environment (derived from data from the Plastics Federation of South Africa).

mostly plastic. Some 20% of South Africans live adjacent to urban areas in informal settlements where adequate waste disposal facilities are lacking. The same problem occurs in neighboring states such as Botswana and Namibia as a result of the large number of products imported from South Africa.

To counter these problems, attempts are being made to reduce the amount of plastic used in disposable applications (260,000 tonnes in South Africa in 1988, Fig. 5). This "source-reduction" approach (Wirka 1988) can be successful, judging by the small amount of litter found in Zimbabwe, where strict currency exchange regulations limit the use of plastics and almost all containers are returnable on a deposit basis. However, there is considerable industry resistance to such changes, despite support for a reduction in superfluous and environmentally damaging packaging by consumer bodies. Concerted public pressure is needed to stem the growth of plastics in disposable applications (Wirka 1988). At present, product substitution is preferred to the use of degradable plastics, which have attendant problems (e.g., Taylor 1979; Wirka 1988).

Almost 10% of South Africa's annual plastic production was recycled during 1988 (including factory scrap; Fig. 5), a greater proportion than that recycled in the United States (1%; Wirka 1988). One mixed-plastics recycling plant producing a wood substitute has recently been established in Cape Town, and there are several primary recycling operations throughout South Africa. However, there is much scope for further recycling, and incentives to return used plastics for recycling are likely to prove successful in limiting littering. There are problems associated with recycling plastics in southern Africa. The relatively small volume of material and the widely scattered markets render many recycling operations uneconomic. Also, in most areas of southern Africa, solid waste disposal using landfill sites remains by far the cheapest disposal technique, although groundwater contamination by leachates from landfills is a potential problem.

Legislation in South Africa is starting to address the problem of inadequate waste disposal. The recently promulgated Environmental Conservation Bill provides for heavy fines and, in some cases, jail sentences for littering and other disposal contraventions. However, it is hoped that voluntary meaures taken by the business sector will obviate the need for further legislation. Awareness campaigns focusing public concern have had considerable success in promoting the use of more environmentally friendly products and practices (e.g., the phasing out of six-pack yokes and shrink-wrapped packaging for bricks, and the printing of warning labels on a variety of disposable plastic products; Dolphin Action and Protection Group 1989), but many problems remain to be solved. It is only through the whole-hearted support of the entire community that the marine debris problem can be diminished.

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INTERNATIONAL EFFORTS TO CONTROL MARINE DEBRIS IN THE ANTARCTIC

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ABSTRACT

Since much of the Antarctic, including the surrounding seas, remains in a relatively pristine state, the monitoring of environmental changes in this area often provides early warning of hazardous global phenomena, e.g., the stratospheric depletion of ozone. Reacting to a U.S. initiative, members of the Commission for the Conservation of Antarctic Marine Living Resources have taken steps to monitor the potential problem of marine debris, particularly from fishing operations. The Commission is joining with the Scientific Committee for Antarctic Research in establishing a program to monitor the effect of plastic pollution and entanglement on marine animals. The initiatives undertaken to establish monitoring programs for marine debris, the results to date, the reasons for their success and future needs in the Antarctic are discussed in this review.

INTRODUCTION

The 1984 Workshop on the Fate and Impact of Marine Debris provided ample warning that marine debris of terrestrial and shipborne origin was widespread in the marine environment and was apparently capable of contributing substantially to increased mortality of marine life (Shomura and Yoshida 1985). Of particular concern was the implication of debris arising from fishing operations (including lost or discarded net fragments, plastic packing bands, lines, and rope) in the harmful entanglement of substantial numbers of animals from many North Pacific populations of pinnipeds: northern fur seal, *Callorhinus ursinus* (Scordino 1985); Steller sea lion, *Eumetopias jubatus* (Calkins 1985); northern elephant seal, *Mirounga augustirostris*, California sea lion, *Zalophus californianus*, and harbor seal, *Phoca vitulina richardsi* (Stewart and Yochem 1985); and Hawaiian monk seal, *Monachus schuainslandi* (Henderson 1985). Fowler's (1985 1987) analyses of the substantial database for northern fur seals even suggested that the mortality of fur seals due to entanglement may be contributing significantly to declining trends (4-8% per year since the mid-to-late 1970's) of the population on the Pribilof Islands.

In R. S. Shomura and M. L. Godfrey (editors), Proceedings of the Second International Conference on Marine Debris, 2-7 April 1989, Honolulu, Hawaii. U.S. Dep. Commer., NOAA Tech. Memo. NMFS, NOAA-TM-NMFS-SWFSC-154. 1990.

To begin addressing the uncertainties surrounding the marine debris problem while mitigating the known impacts, the 1984 workshop recommended, among other things, that educational efforts be undertaken to advise user and interest groups of the nature and scope of the issue. It was thought appropriate to include relevant international groups in this educational approach. The 1984 workshop also agreed that additional efforts should be undertaken to establish the severity of the debris problem in areas other than the North Pacific. Consequently, the stage was set for aggressive initiatives at several international forums to determine if the marine debris problem was occurring in other ocean basins.

Given the apparent adverse impact of marine debris, especially from fishing operations, upon North Pacific pinniped populations, it seemed reasonable to focus attention upon the Antarctic, where large populations of pinnipeds also occurred. In response to the establishment of a substantial international trawl fishery in the Antarctic during the 1970's, the Convention and Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) had come into force in 1982. The United States was a founding member of CCAMLR and brought the marine debris issue to the Commission's attention at its third annual meeting, in September 1984, 4 months after the convening of the marine debris workshop.

U.S. ANTARCTIC INITIATIVES

Organization and Mandate of CCAMLR

The CCAMLR is a unique international agreement which implements an ecosystem approach to the conservation and management of marine living resources found in the Antarctic. The CCAMLR convention area includes the marine area south of the Antarctic Convergence, the boundary between lat. 48° and 60°S which separates cold Antarctic waters from warmer subantarctic waters (Fig. 1). The area south of this boundary is considered the Antarctic marine ecosystem. The convention applies to "the populations of finfish, mollusks, crustaceans, and all other species of living organisms, including birds, found south of the Antarctic Convergence" (Anonymous 1988a).

The CCAMLR currently comprises 20 member nations, and an additional 4 nations have acceded to the convention but have not yet been accorded membership (Anonymous 1988a). The major operational units which undertake the convention's responsibilities (Fig. 2) are the Commission for the Conservation of Antarctic Marine Living Resources (the "Commission") and the Scientific Committee for the Conservation of Antarctic Marine Living Resources (the "Scientific Committee"). The work of these bodies is facilitated by a permanent secretariat which resides at CCAMLR headquarters in Hobart, Tasmania, Australia.

The convention mandates a management regime which ensures that harvesting of Antarctic species, such as finfish and krill, is conducted in a manner that considers ecological relationships among dependent and related species. Article II of the convention specifically requires the Commission to follow four basic principles of conservation (Sherman and Ryan 1988):

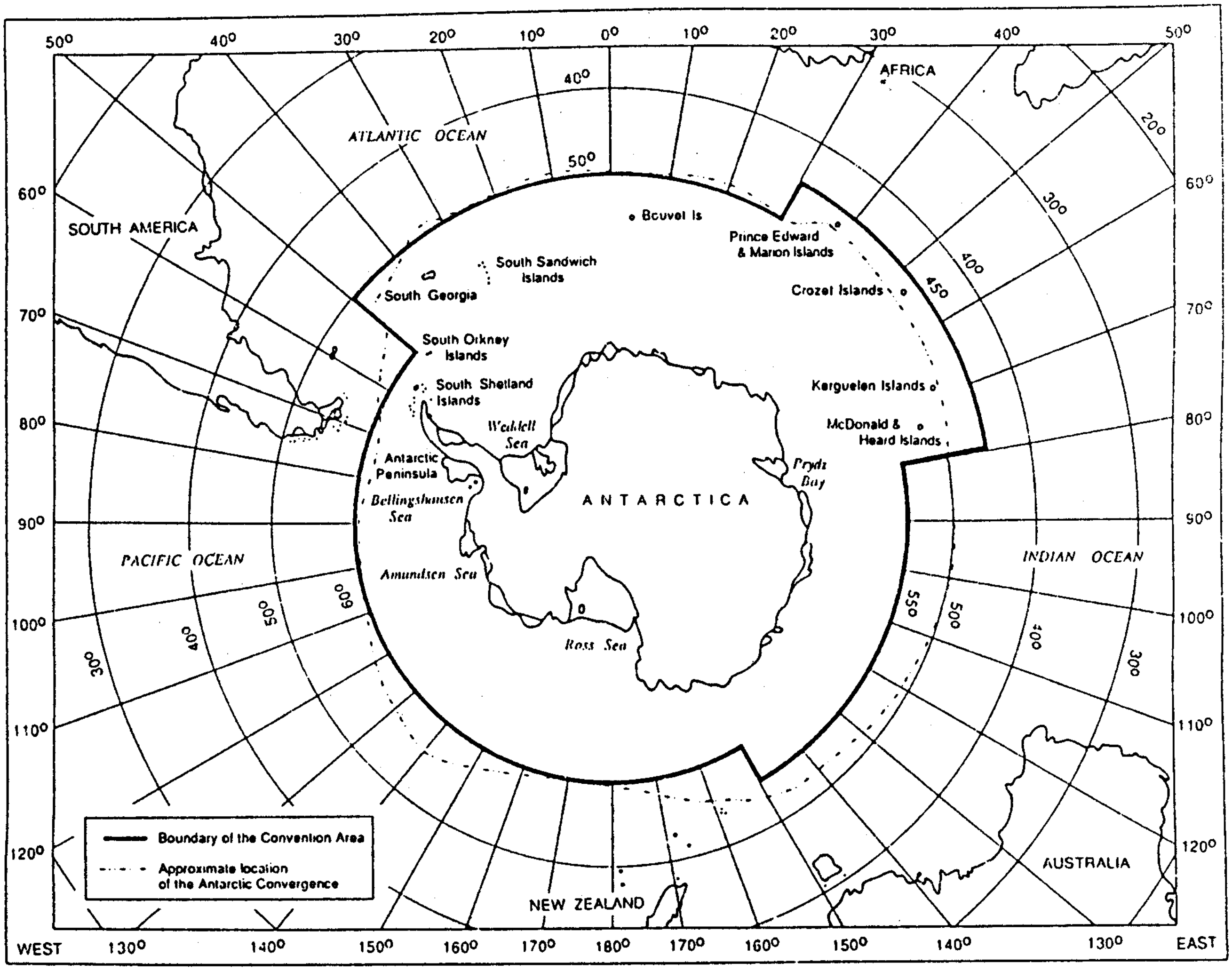

Figure 1.--Boundary of the area under the jurisdiction of the Convention for the Conservation of Antarctic Marine Living Resources (Anonymous 1988a).

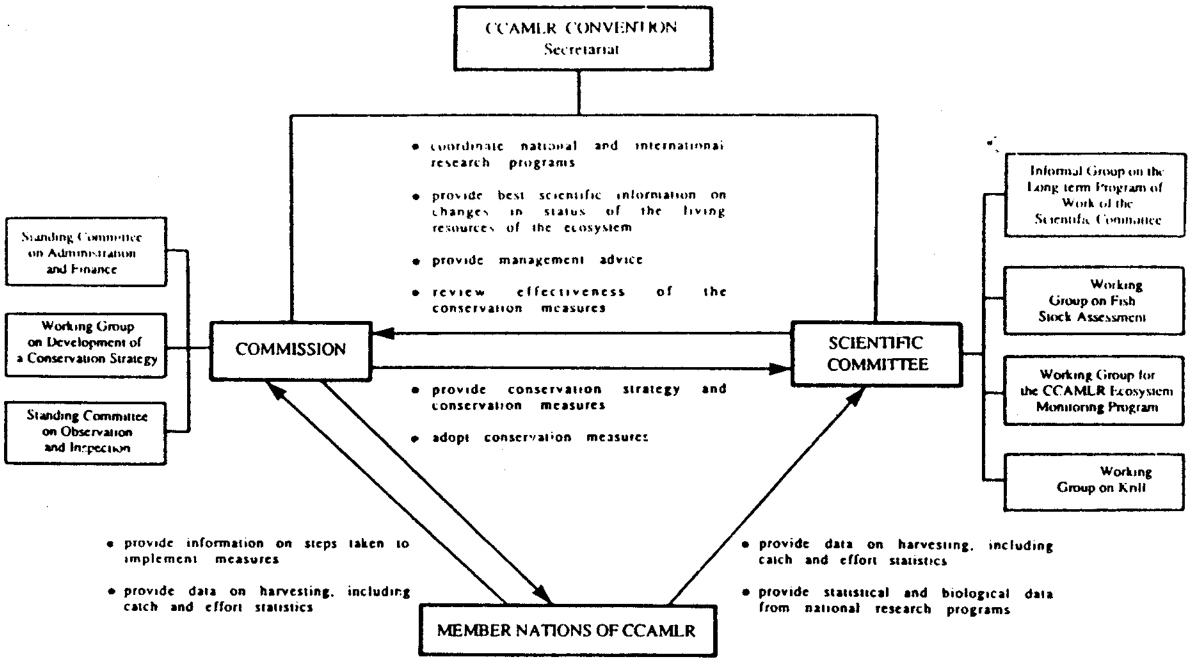

Figure 2.--Organizational structure of the Convention for the Conservation of Antarctic Marine Living Resources (after Sherman and Ryan 1988).

1. To prevent any harvested population from falling below the level that ensures the greatest net annual increment to stable recruitment;

2. to maintain the ecological relationships between harvested, dependent, and related populations of Antarctic marine living resources;

3. to restore depleted populations; and

4. to prevent or minimize the risk of changes in the Antarctic marine ecosystem that are not potentially reversible over two or three decades.

It was within this ecosystem context that the United States was able to raise the marine debris issue. In particular, the fourth principle gave rise to a powerful argument that the Commission must act to prevent irreversible changes in the Antarctic marine ecosystem which might arise from harvesting activities, including the loss or disposal of debris resulting from those activities. At least the Commission found itself compelled to give the issue due consideration when the United States introduced it at the 1984 annual meeting.

U.S. Proposals and CCAMLR Response

1984 Initiative

In 1984, the U.S. delegation submitted and the Commission considered a paper entitled "Assessment and avoidance of incidental mortality of Antarctic marine living resources." This document indicated that, while there did not seem to be any problem with entanglement of animals in lost or discarded fishing gear and other marine debris in the convention area, there was growing evidence in other areas, e.g., the North Pacific, that significant numbers of nontarget marine organisms were being caught and killed in such debris, as well as being caught and killed incidentally during certain fishing operations. The Commission agreed with these conclusions, and asked its members to undertake steps to study and assess the possible sources, fates, and effects of marine debris in the convention area, including (Anonymous 1984):

- reviewing and reporting on past encounters with marine debris at sea or at coastal research stations;
- reporting on the nature of problems arising from debris such as fouled propellers or entangled animals, and
- periodically surveying beaches at research stations or other areas to ascertain the types, quantities, and sources of debris accumulating there.

The Commission also agreed that members should report on the number of birds, marine mammals, and other nontarget species taken incidentally during fishing operations. Moreover, members were asked to inform their nationals of international and national laws prohibiting or restricting the disposal of netting and other potentially hazardous materials at sea and to report on measures taken to assess, avoid, and mitigate incidental mortality of Antarctic marine life. Finally, it was agreed to include this item on the agenda for the 1985 meeting and to consider the desirability of marking fishing gear for identification purposes, as well as restricting the use of gillnets in the convention area.

In 1985, the Commission received formal reports from four members, including the United States, on steps taken in response to the basic monitoring program established in 1984. A number of oral reports were received as well, and the United States submitted a preliminary report of the proceedings of the 1984 Workshop on the Fate and Impact of Marine Debris. Based upon this information, the Commission again concluded that there was no evidence that significant quantities of fishing gear, binding material, or other hazardous debris had been or were being lost or discarded in the convention area (Anonymous 1985). However, given the compelling evidence for such debris in other ocean areas, including areas adjacent to the convention area, and of the extent of its harmful effects to marine life and of its hazards to navigation, the Commission agreed to continue its monitoring program.

The Commission further agreed that members should continue studying the feasibility and desirability of marking fishing gear and of maintaining inventories of such material brought into the convention area. However, given that there were no substantial gillnet operations in the area at the time, the Commission concluded that prohibiting the use of gillnets as a preventative measure could interfere unnecessarily with the Commission objective of assuring the rational use of resources. The Commission did agree to keep the matter under review.

1986 Initiative

At the 1986 meeting, the Commission received reports from members on monitoring results and the United States submitted a paper proposing additional steps for ensuring that accidental and incidental mortality of marine life did not become a problem in the convention area. While the information provided continued to indicate that incidental and accidental mortality of living marine resources did not appear to be a problem, the Commission recognized that such mortalities, including those resulting from entanglement in or ingestion of marine debris, could interfere with efforts to achieve the objectives of the convention (Anonymous 1986). As a consequence, the Commission agreed to new measures to reduce or prevent the at-sea discarding of fishing and other hazardous debris:

- Members would take steps to ratify and implement both optional Annex V of the 1978 Protocol to the International Convention for the Prevention of Pollution from Ships (MARPOL) and the International Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (London Dumping Convention); and

- the secretariat would prepare drafts of an information brochure to advise fishermen, researchers, and others working in the convention area of the hazards of marine debris; and of a placard for displaying on ships which listed the "do's and don'ts" for storing, handling, and discarding refuse.

The Commission agreed to continue its monitoring provisions and the collection of incidental catch data. Moreover, it agreed to undertake three new monitoring steps (Anonymous 1986):

1. recording and reporting fishing gear lost in the convention area;

2. if feasible, collecting and safely disposing of marine debris encountered; and

3. collecting samples of marine debris along with pertinent data, including species and numbers of entangled marine animals, for archival by the secretariat.

At the 1987 meeting, progress on all agreed monitoring measures was reviewed, and the Commission closely examined the information on lost or discarded fishing gear obtained from national reviews of such data and from beach surveys in the convention area. Although several members observed no marine debris or entanglement problems, others reported sightings of debris consisting of fishing buoys, gas bottles, plastic containers, trawl net fragments, and plastic packing bands (Anonymous 1987). Moreover, two fur seals, *Arctocephalus gazella*, were seen entangled in derelict fishing nets and a third in longline gear. The Commission agreed not only to continue all elements of the monitoring program, including new steps agreed upon in 1986, but also to establish the issue of incidental/accidental mortality of Antarctic marine living resources as a standing item on the agenda for subsequent annual meetings.

The Commission also reviewed in 1987 the secretariat's drafts of an information brochure and a placard for display on vessels operating in the convention area. The secretariat was authorized to publish the agreed texts and members were urged to give these the widest possible circulation. Moreover, given that Annex V to the MARPOL Convention would prohibit or control the disposal of debris arising from fishing operations in the convention area, members were again specifically urged to ratify and implement this international measure.

In 1988, the Commission received further reports from members regarding loss of trawl cod ends and sightings of other derelict debris, including net fragments and packing bands. Moreover, five fur seals, *A. gazella*, were seen entangled in derelict fishing gear and two adult male fur seals died after becoming entangled in trammel nets (Anonymous 1988b). The Commission agreed to continue all elements of its monitoring program but noted that the reporting of incidental mortality as recommended in 1986 had been inadequate so far.

Also in 1988, the secretariat published and distributed the information brochure and placard for display on the ships of all member nations. As requested by the Commission, the U.S. has made these available to scientists and others working in the Antarctic and to the operators of vessels entering the convention area, including the National Science Foundation, the U.S. Coast Guard, and the National Oceanic and Atmospheric Administration.

FUTURE NEEDS AND ACTIVITIES

Improving Monitoring Efforts

The assumption is often made that much of the Antarctic, including the surrounding seas, remains unsullied by human activities. Consequently, if significant environmental changes are observed there, it is often presumed that these may be resulting from significant environmental perturbations occurring elsewhere on the globe, e.g., the stratospheric depletion of ozone resulting from the production and use of chlorofluorocarbon compounds in the Northern Hemisphere (Anonymous 1988e). The evidence reviewed so far by the Commission would tend to indicate that the marine debris problem in the Antarctic is minimal. That is, it would appear that the levels of debris discarded by vessels in the convention area or the amount brought in by circulation or by other means from other ocean basins have not yet been sufficient to generate major problems for Antarctic marine life.

However, recent information suggests that the level of CCAMLR's monitoring efforts to date may not have been sufficient to ascertain the levels and consequences of marine debris effectively. The Bird Biology Subcommittee of the International Council of Scientific Unions, Scientific Committee for Antarctic Research (SCAR) concluded that a high proportion of Antarctic seabirds had ingested plastic particles, that the incidence was increasing in at least some species in the Southern Ocean and that the problem was particularly acute for procellariform species which accumulate rather than excrete plastics (Anonymous 1988d). Van Franeker and Bell (1988) and Ainley et al. (1990) suggested that the source of the ingested plastic is from wintering areas outside the Antarctic. The SCAR Group of Specialists on Seals also noted that entanglements of Antarctic fur seals in discarded fishing gear had been reported from several areas around the Antarctic, including South Georgia, the South Shetland, Crozet, Marion, Heard, and Bouvet Islands (Anonymous 1988c). Consequently, one might conclude that CCAMLR has so far been seeing only the tip of the marine debris iceberg.

Taking note of CCAMLR's early monitoring initiatives in this area, both SCAR groups requested the Commission's assistance in examining the problem further. The SCAR's Bird Biology Subcommittee requested that CCAMLR consider initiating programs to monitor the level and effects of plastic pollution in subantarctic and Antarctic seabirds, considering both ingestion of plastic particles and entanglement. The SCAR Group of Specialists on Seals also requested that CCAMLR seek detailed information on the frequency of occurrence and nature of entanglement events involving seals in order to identify the causes of entanglement and trends in the frequency and extent of such entanglement over time (Anonymous 1988b).

At its 1988 meeting, however, the Commission noted that its monitoring program had three shortcomings relevant to SCAR's requests (Anonymous 1988b):

1. It did not address the problem of ingestion of plastics.

2. It did not specifically provide for quantitative and detailed reports of entanglement when fishing operations were not directly involved.

3. It may not provide adequately detailed information on incidental mortality during fishing operations to enable assessment of the problem or to monitor changes quantitatively.

To see if these shortcomings could be rectified so that assistance might be given to SCAR, the Commission authorized the chairman of the Scientific Committee to open a dialogue with the relevant SCAR groups (Anonymous 1988b). In particular SCAR's advice was sought (and provided at the 1989 meeting (Anonymous 1989)) on how the levels and effects of ingestion of plastics by Antarctic seabirds could be monitored, how quantitative surveys could be conducted to determine the incidence, causes, and effects of marine mammal entanglements, and how the CCAMLR system of reporting incidental mortality might be improved in order to precisely determine the incidence, causes, and effects of such mortality. This new interaction between the Commission and SCAR should pave the way for greatly improving CCAMLR's pioneering efforts to monitor the marine debris problem.

Improving the Coordination of Efforts

The CCAMLR's exhortations on behalf of MARPOL apparently paid off, since Annex V came into force in December 1988 (Anonymous 1988e). It is now illegal for ships registered in the 35 ratifying nations, including the United States, to dump plastic debris such as that arising from fishing operations into the sea.

To become even more effective in controlling the marine debris problem in the Antarctic, it would seem desirable for the Commission to begin coordinating its actions with the International Maritime Organization (IMO). The IMO is the specialized agency of the United Nations which oversees implementation of MARPOL and the London Dumping Convention. This possible coordination, along with the pending cooperation between the Commission and SCAR, points out a growing need for an effective coordinating mechanism on this and other Antarctic issues.

In fact there has been a continuing debate among the Antarctic Treaty consultative parties (ATCP's) regarding the need for an Antarctic Treaty secretariat (Kimball 1987). The ATCP's favoring such a secretariat point to the increasing variety and complexity of issues being dealt with which require more numerous and more frequent communications within and between instruments of the Antarctic Treaty system, including CCAMLR, as well as with other relevant international organizations and elements of the outside world. The growing number of players becoming involved in dealing effectively with the issue of marine debris in the Antarctic (CCAMLR, SCAR, and IMO) may well provide another argument in favor of a secretariat.

DISCUSSION

Despite possible shortcomings and problems, it would appear that substantial progress has been made in trying to deal with the issue of marine debris in the Antarctic. The CCAMLR's monitoring program has evolved quite rapidly since the United States introduced the issue in 1984. Although the program is, perhaps, not yet as quantitative as some scientists would wish, the Commission is at least in a very good position to ascertain and evaluate trends in levels of debris and entanglements of marine life.

Under the convention, the Commission must take all of its decisions by consensus, which has led at times to a lowest-common-denominator-syndrome and resulted in somewhat ineffectual measures. So, the progress made with respect to marine debris might seem all the more remarkable unless one considered it in the light of the unique nature of the convention itself. The CCAMLR not only requires an ecosystem approach to the conservation and management of living marine resources but also sets forth the principle that the Commission must act to prevent or minimize irreversible changes to that ecosystem. More than anything, these unique provisions probably account for the success achieved on the issue.

The philosophy behind CCAMLR provides great flexibility and a basis for dealing with many kinds of marine conservation issues, not just those dealing with the use of resources. This is a powerful tool, and the convention should be taken seriously as a model for all future resource use conventions and agreements in other ocean areas.

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COOPERATIVE RESEARCH ON PETROLEUM POLLUTION IN THE CARIBBEAN: THE CARIPOL PROGRAM

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ABSTRACT

The CARIPOL program is a cooperative regional effort to assess the state of pollution of the marine environment in the Caribbean and adjacent regions. In its initial phase, CARIPOL has concentrated on the assessment of petroleum pollution through the monitoring of three easily determined variables: the occurrence of tar aggregates on beaches, of floating tar at sea, and of dissolved or dispersed petroleum hydrocarbons. A data base of greater than 7,000, 680, and 1,460 data points, respectively, for the three variables has been accumulated through submissions from 14 countries in the region.

Tar on beaches is a serious problem in the region, especially in the Windward islands, the Cayman islands, and the archipelago of Aruba, Curacao, and Bonaire where loads of up to 1 kg of tar/m of beach front have been reported. Other affected areas include the ease coast of Florida, the Yucantan peninsula, and Campeche Sound. The occurrence of floating tar has been closely correlated with tanker traffic in areas such as the south coast of Puerto Rico and the Straits of Florida. Dissolved and dispersed petroleum hydrocarbons reach critical levels only in enclosed waters such as bags and harbors subject to intense maritime traffic or industrial petroleum sites.

The CARIPOL program has now embarked upon a second phase to assess the accumulation of petroleum hydrocarbons in sediments and organisms. Initial results indicate that although these compounds are rapidly degraded when released to the water, they may persist for extended periods upon reaching marine sediments.

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